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STRESS ANALYSIS OF CERAMIC TURBINE BLADES BY FINITE ELEMENT METHOD PART I

by

Lael Ray Easterling

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Thesis Advisor: G. Cantin

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Stress Analysis of Ceramic Turbine Blades by Finite Element Method - Part I

by

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Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1968

Submitted in partial fulfillment of the requirements for the degrees of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

and

MECHANICAL ENGINEER

from the

NAVAL POSTGRADUATE SCHOOL
March 1978

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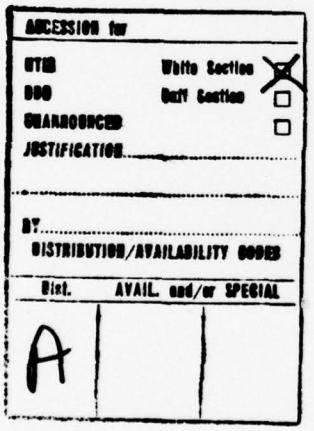
ABSTRACT

The search for more efficient gas turbine engines has led to the proposal for the replacement of metal high temperature components with ceramic components. Essential to this effort is the numerical analysis of proposed designs. This thesis report describes the model discretization of a proposed blade design, the development of pre- and post-processors for the ADINA finite element code and the initial stress analysis of the modeled blade.



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I. INTRODUCTION

The need to increase fuel efficiency of gas turbines has led to a sizable research investment into suitable materials and designs of ceramic gas turbine components to replace high temperature resistant superalloys. This replacement is envisioned to yield a threefold benefit:

1) The refractory characteristics of ceramics will allow a greater source-sink temperature differential increasing plant efficiency without penalizing overall performance by requiring increased cooling air bled off the compressor.

2) The lower specific weight of ceramics relative to the metal components to be replaced will lower plant weight thereby increasing the plant's power-to-weight ratio.

3) Ceramic constituent components are, in general, domestically available giving them a strategic edge over superalloys.

The basic problem preventing realization of these benefits is the brittle characteristic of ceramics. Since the brittle property is associated with the desirable refractory characteristic, material research and development can only be expected to yield marginally better ceramics in the near future. Any short term success will, therefore, be a result of design innovations which will compensate for the brittle nature of ceramics to allow their use for components which have formerly been engineered on the basis of use of ductile materials.

Essential to this design effort is the use of numerical techniques to model proposed designs and develop alternative criteria with the ultimate goal of minimizing stress concentrations which key catastrophic brittle failure. This thesis describes the efforts of the author to utilize the computer hardware and software available at the Naval Postgraduate School (NPS) to analyze stress distributions in gas turbine ceramic replacement components. Time constraints dictated limiting the scope of analysis to the modeling and development of pre- and post-processors for a proposed first stage ceramic turbine blade subjected to centrifugal loading.

A turbine blade design, developed by the AIRESEARCH division of GARRETT CORPORATION under a Navy managed contract for development of a one-hundred hour test gas turbine engine using ceramic components for the combustor, stator vanes, and rotor blades, was used in this work. Stress distribution analyses were centered around the "Automatic Dynamic Incremental Nonlinear Analysis" (ADINA) code developed by Dr. Klaus-Jurgen Bathe of the Massachusetts Institute of Technology [Ref. 1] as implemented on the NPS IBM 360-67 computer system. The bulk of the modeling effort was accomplished on a Hewlett-Packard 9830 desk top calculator with associated graphics equipment and the PSAP1 graphics package [Ref. 2] implemented on the NPS computer by Lt. Adrian Kibler. Material properties were those of hot-pressed Silicon-Nitride provided by AIRESEARCH. Post-processing graphics utilized a

contour plotting routine developed by Gary L. Giles of Langley Research Center [Ref. 3] and implemented on the NPS computer by Dr. Gilles Cantin of NPS and the author.

The complete analytical efforts were divided into four major categories:

1) development of a discretized model of the blade and attachment design.

2) development of a pre-processor to calculate consistent centrifugal loads.

3) modification of the ADINA code to yield a maximum of stress output locations.

4) execution of ADINA with model developed and elaboration of post-processors to help in the interpretation of results.

II. ANALYTICAL MODEL DEVELOPMENT

Developing the finite element mesh of the complex geometric shapes incorporated in the blade was a compromise between geometric accuracy, mathematical compatibility and economy of effort. Using drawings provided by AIRESEARCH [Refs. 4, 5, 6], a mathematical definition of the airfoil and the root was developed separately and then mated using twenty node bricks arranged compatibly throughout the entire assembled mesh.

A. BLADE NOMENCLATURE

Figure 1 illustrates the nomenclature used in this paper to describe the gas turbine blade model and the reference system used to define the geometry. The portion of the component aerodynamically designed to be in the gas flow is termed the airfoil. The fillet is the transition section in between the airfoil and the attachment root designed to minimize stress concentrations. The attachment root (also termed the dovetail) forms the base of the airfoil, provides radial and tangential placement of the blade, and transmits the forces developed by the gas flow to the disk. A right-hand cartesian coordinate system was used to describe the geometry. The X-axis coincided with the turbine axis-of-rotation. The Z-axis coincided with the stacking axis for the airfoil profiles. The Y-axis was then mutually perpendicular to the X- and Z-axis, with the system origin on the rotation axis.

B. GEOMETRIC DEFINITION

1. Airfoil

Reference 4 provided sixty-two perimeter points for x-y plane cross-sections at ten z-levels from z=3.1 to z=4.0 inches. Linear fairing was prescribed for machining between cross-sections in order to facilitate manufacture. The airfoil tip level of 3.874 inches and z-level 3.385 inches (level of beginning of fillet definition) were plotted and stored for use in discretizing the airfoil. Because of the linear fairing technique, intermediary points were left to the ADINA code feature of node generation for definition.

2. Fillet

The fillet geometry consisted of two radii; 0.3 inch and 0.1 inch. The locus of centers of the 0.3 inch part of the fillet was at a constant level of 3.385 inches. The arc subscribed was tangent to the linear airfoil. The locus of centers of the 0.1 inch radius arc was centered such that the arc subscribed was tangent to both the 0.3 inch radius fillet section and the base which was considered to be a 3.2 inch radius right circular cylinder about the axis of rotation. This double radius design was chosen in order to reduce the possibility of stress concentrations by approximating an elliptic geometry.

Geometric definition of the fillet was made in sixty-two, two-dimensional planes parallel to the Z-axis and containing the normal vector to each of the sixty-two

defined perimeter points at z=3.385 inches (Figure 2a). The following described algorithm was developed to define the limiting points illustrated by Figure 2b.

a. Determination of the External Normal

A second degree Lagrange interpolating polynomial was passed through three successive perimeter points at the cross-section z=3.385 inches, and the first derivative was evaluated for the middle point in order to determine the slope of the tangent vector at this point. The negative reciprocal of the derivative is the slope of the line normal to the analysis point. Taking the y-component as -1 and the x-component as the derivative (dy/dx), a normal vector was defined. This vector was then normalized to give a unit vector. The analysis point was tested to determine the desired coefficient signs in order to define the normal with the direction external to the body of the airfoil. This procedure was carried out for each perimeter point, thereby defining sixty-two normals from the airfoil.

b. Locus of 0.3 Inch Radius Centers

The coordinate system was translated and rotated to yield a working plane which was parallel to the Z-axis and contained the unit normal vector for the point being analyzed. The curvature center was adjusted in this working plane at z=3.385 inches such that the 0.3 inch arc was tangent to the linear airfoil surface. These contact points, defining the start of fillet curvature, were transformed to the original coordinate system for future use.

c. Locus of 0.1 Inch Radius Centers

The 0.1 inch radius curvature centers were defined in each of the sixty-two working planes by use of a Newton iteration scheme to adjust the center of curvature such that the subscribed arc was tangent to both the 0.3 inch arc and the top of the root. These points of tangencies were determined, transformed to the original coordinate system and stored.

d. Definition of Perimeter Point at Arbitrary Z-Level

Using the above determined points (Figure 2b), an algorithm was developed which took as input any desired z-level in the fillet region, tested for the correct definition of geometry for that level and yielded an array of sixty-two perimeter surface points for that level.

Information from the above procedure allowed the definition of a sixty-two point perimeter at any z-level of an airfoil or fillet cross-section parallel to the x-y plane.

3. Attachment Root

The attachment root geometry was defined in a vertical plane containing the stacking axis and perpendicular to the horizontal longitudinal centerline of the body of the root which has a broach angle of 23^{o} relative to the axis of rotation (Figure 3). Nine different geometries consisting of straight lines and arcs of circles were defined by Ref. 6 in this plane for the perimeter of the root. These goemetries were mathematically defined, and the limiting point coordinates of each segment were determined. This

shape was projected into the fore and aft faces of the disk. Symmetry conditions allowed simple manipulations of coordinates in order to define the shape of the entire attachment root. An algorithm was developed to define 231 points on any desired horizontal surface.

C. ANALYSIS MESH DISCRETIZATION

Major considerations in the development of the analysis model were to define a mesh which adequately described the geometry of the blade and yielded sufficient data points for meaningful evaluation, without making the mesh so fine as to require an inordinate amount of computer time for solution. Twenty node bricks were chosen for use throughout the mesh because of their capability of accurately defining any second order geometric curve (used almost exclusively by the designers of the blade) and their isotropic sensitivity to the applied loads.

The airfoil was represented by a mesh of twelve elements arranged one deep, three high and four long (Figure 4). The top two layers defined the linearly faired section, and the bottom row defined the fillet region. Choice of nodal point coordinates were made with the assistance of plots of horizontal cross-sections of points defined by geometry definition algorithms.

Chosen for the attachment root representation were nominal three deep, four long layers of elements defining each different vertical geometric segment (Figure 5). The exact

make-up of the root mesh was controlled by the mating of the airfoil with the attachment root which caused significant distortions because the design definition of the fillet base extended beyond the limits of the top surface of the attachment root. This mis-match of geometries necessitated brute force adjustment of nodal point coordinates in order to mate the two regions into a single consistent mesh.

Once the mating process was accomplished, all the chosen nodal points and the element connectivities were card punched in the format required by ADINA. The ADINA deck was then used as input to the PSAP1 graphics package in order to de-bug the mesh. After adjustments were made to yield a visually satisfactory mesh, a trial analysis was run which brought to light numerous mathematical difficulties caused by the distortions resulting from the mating of dissimilar geometries. These were corrected, and the final mesh (Figure 6) was considered ready for analysis.

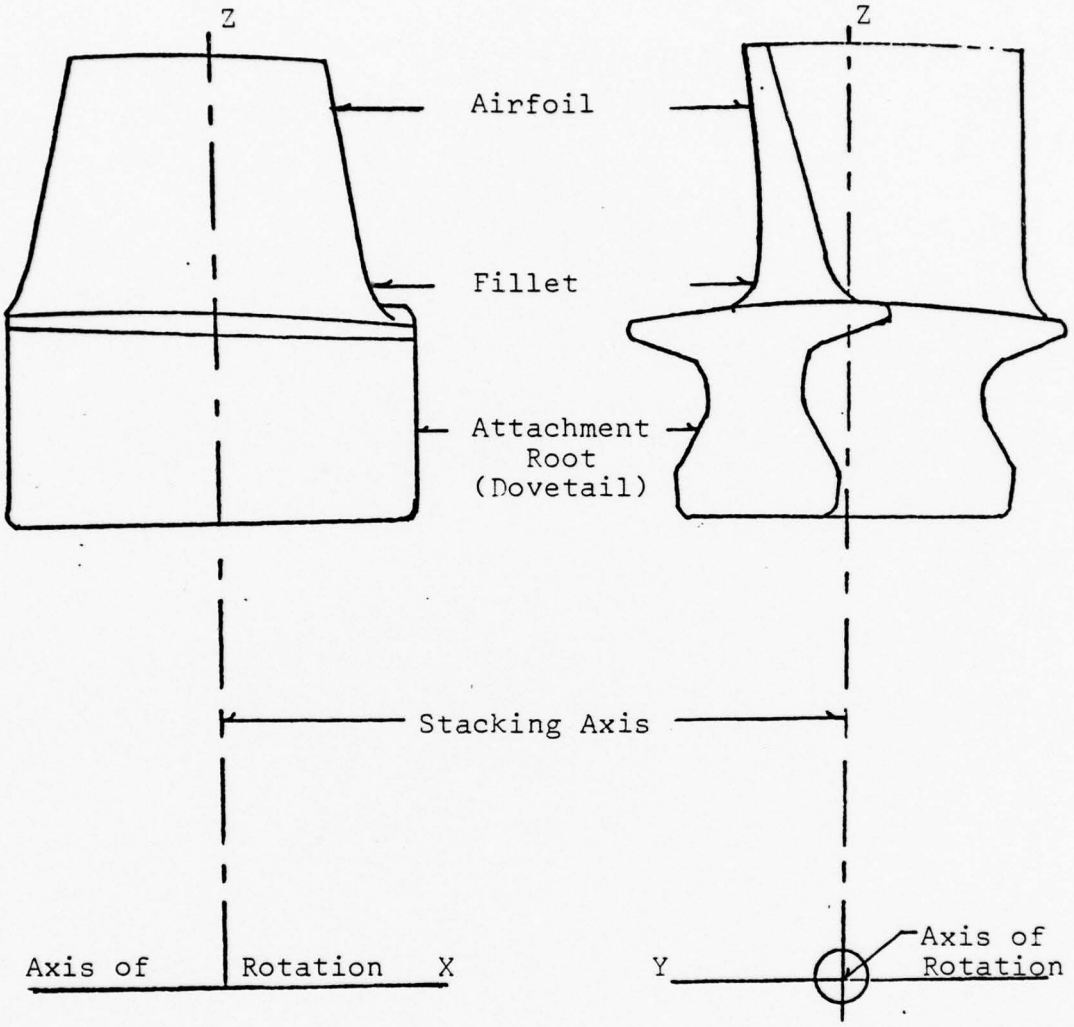

Figure 1. Illustration of Nomenclature and Reference System of Turbine Rotor Blade.

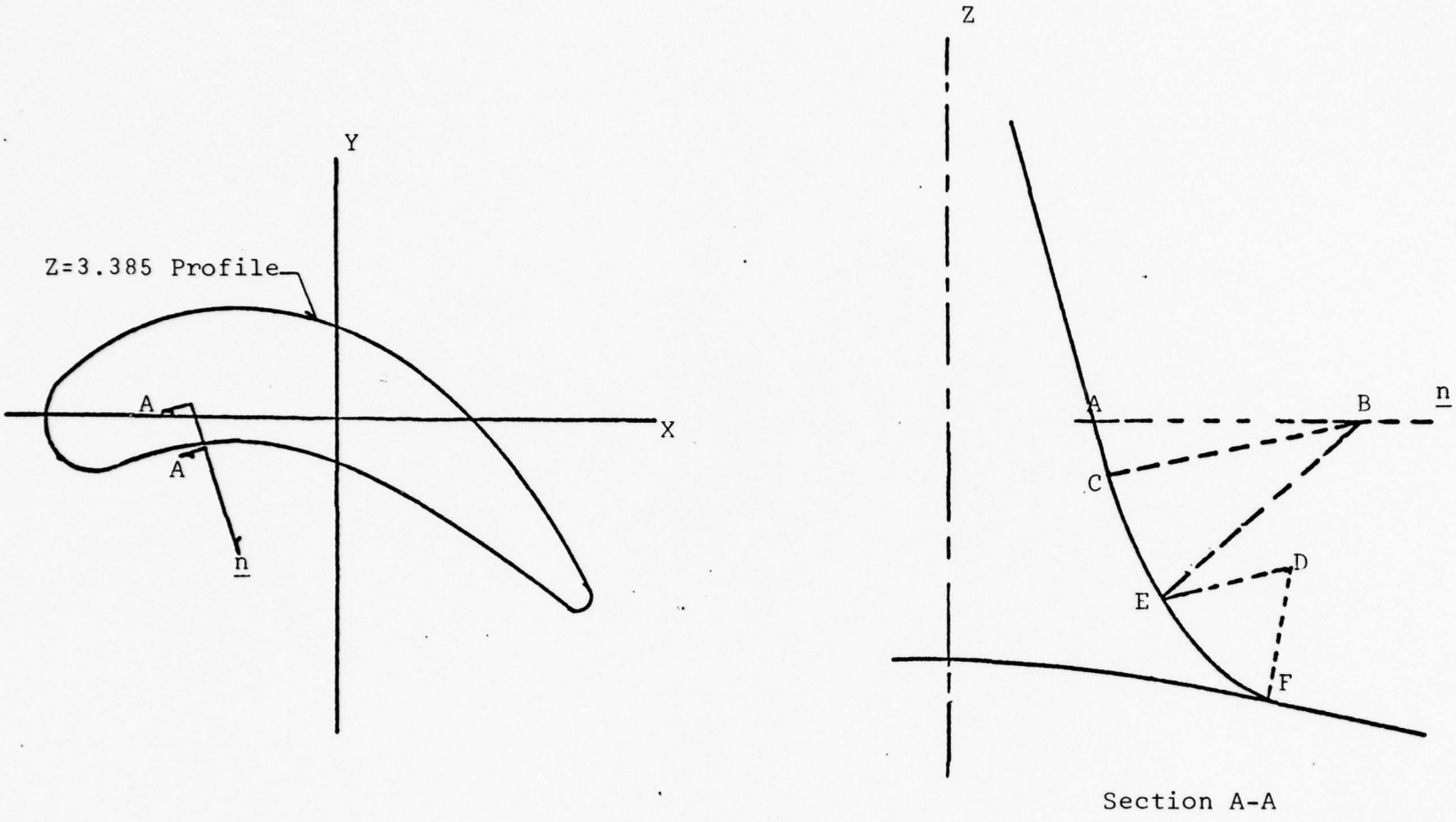

Figure 2. Illustration of Plane in Which Fillet Geometry is Defined.
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Definition of nomenclature for Figure 2

$\underline{n}$ = outward pointing normal

A = level z = 3.385 inches

B = center of 0.3 inch fillet radius curvature

C = point of tangency between linear airfoil and fillet curvature

D = center of 0.1 inch fillet radius curvature

E = point of tangency between 0.3 inch fillet curvature and 0.1 inch fillet curvature

F = point of tangency between 0.1 inch fillet curvature and attachment root surface

Figure 2. Continued, Page 2 of 2.

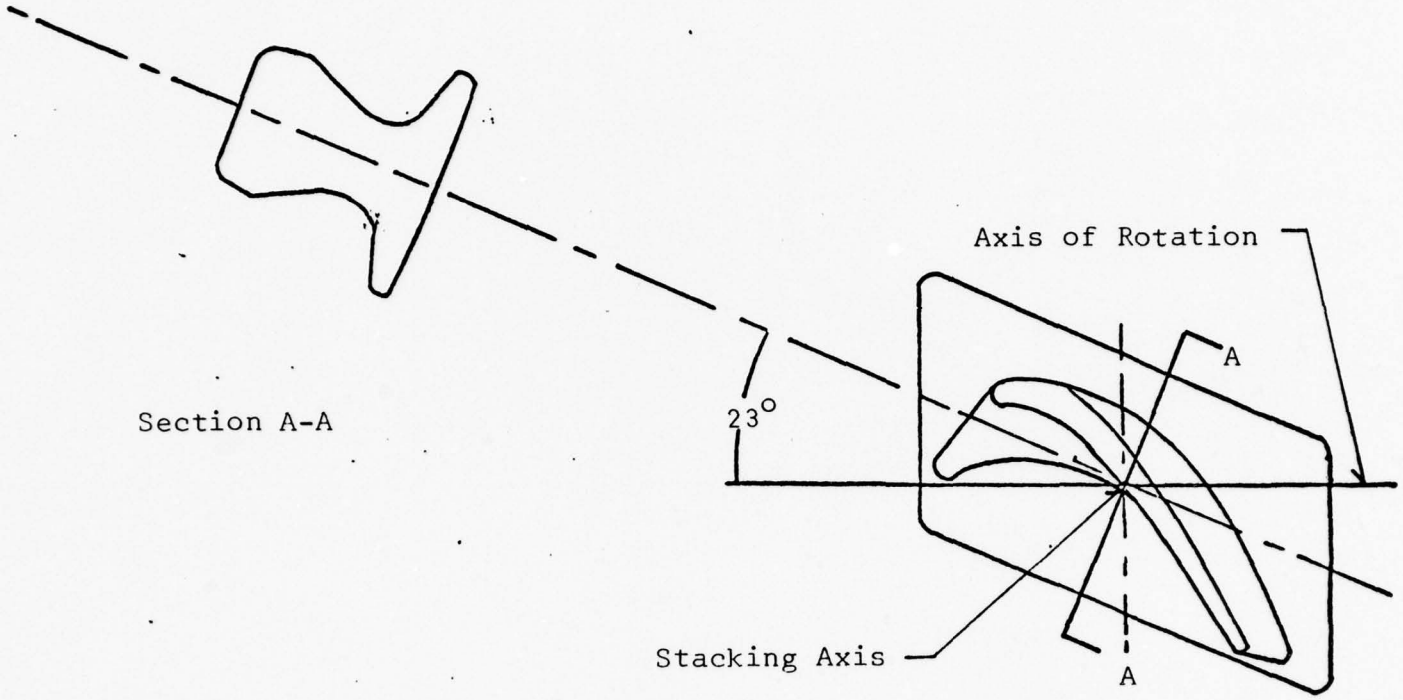


Figure 3. Illustration of Plane in Which Attachment Root Geometry is Defined.

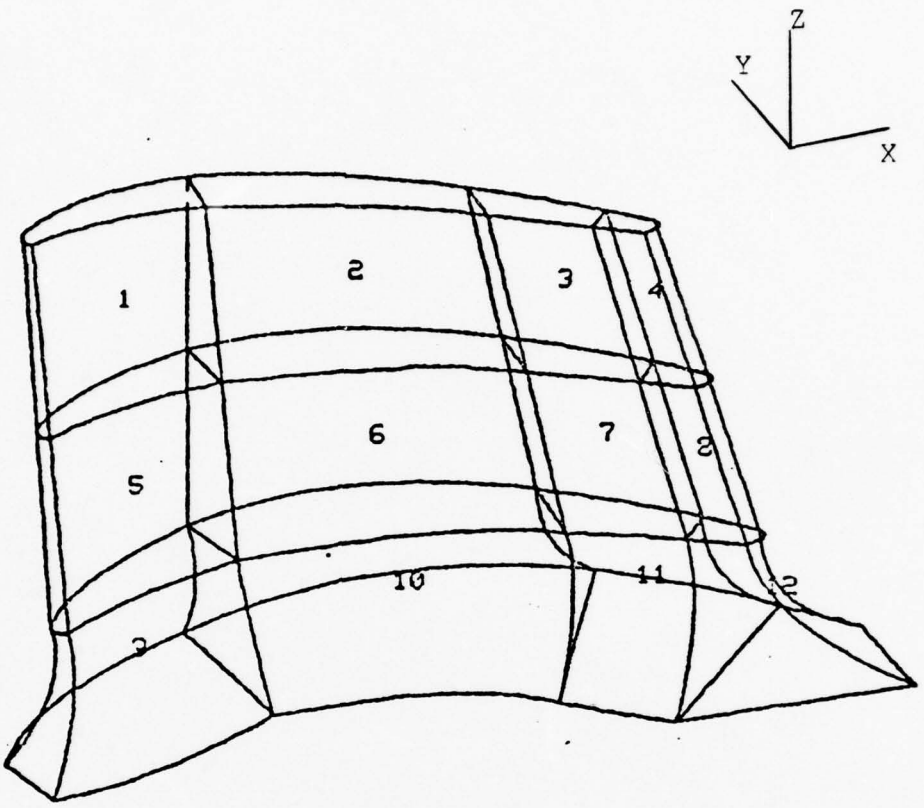
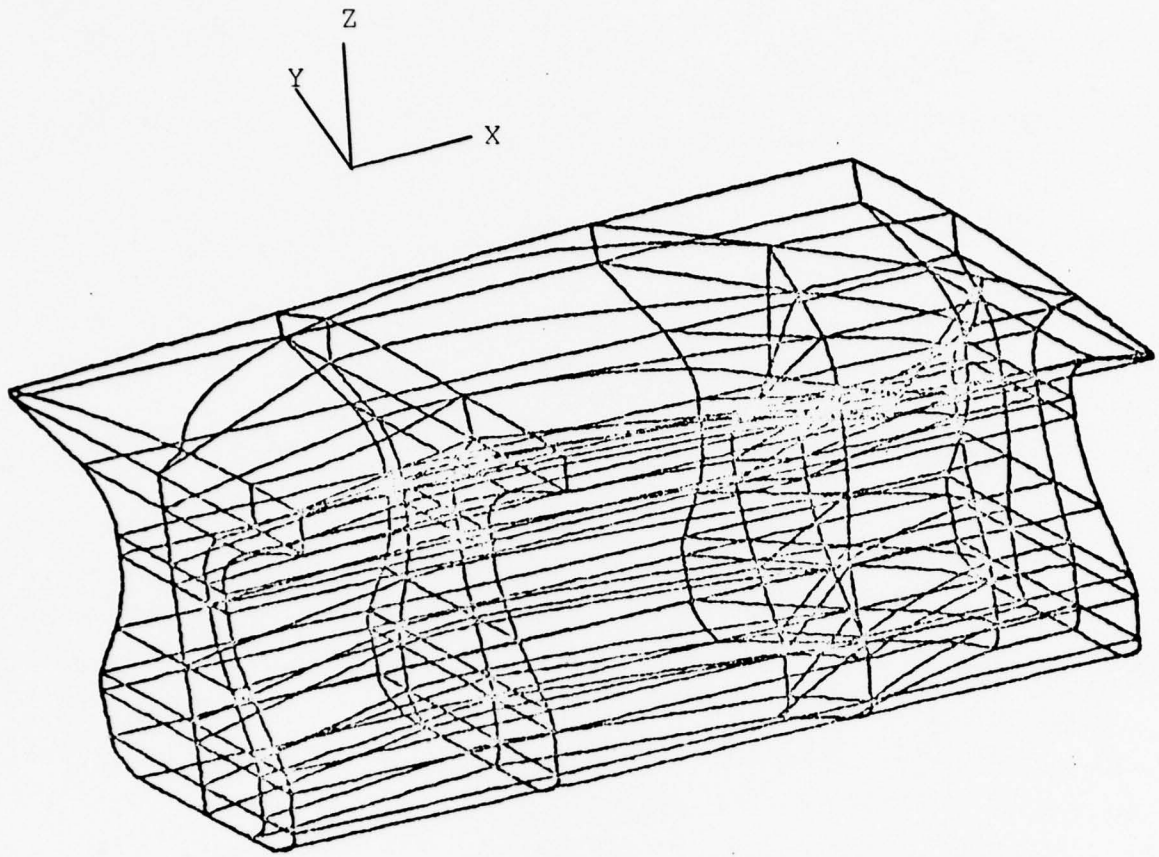
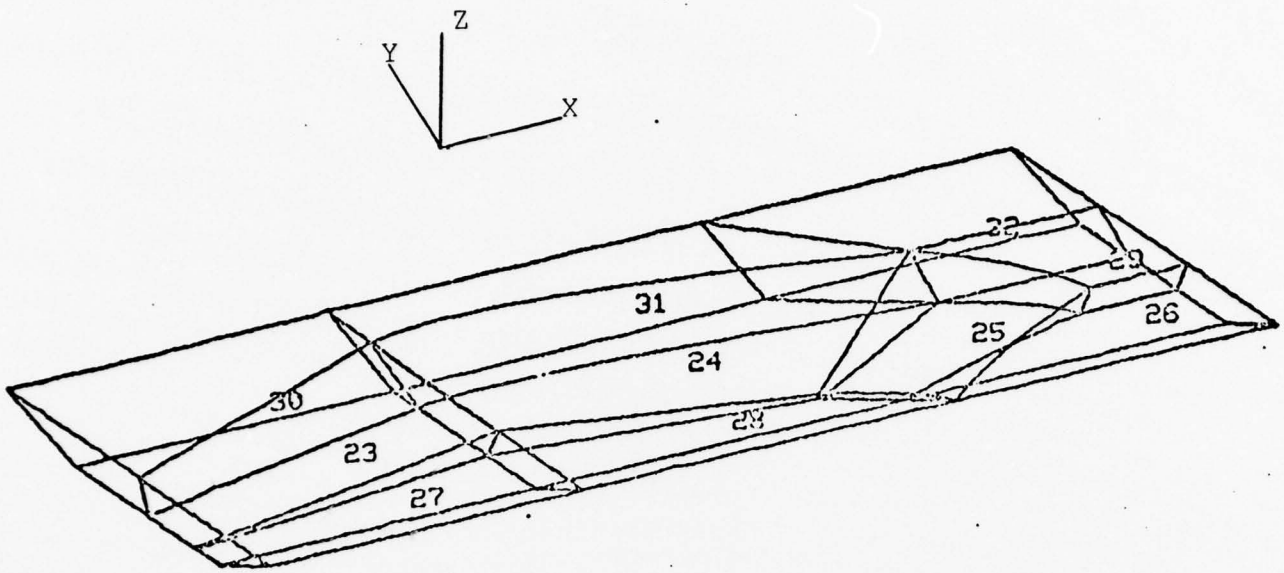


Figure 4. Airfoil Mesh, Elements 1 through 12.



(a) Elements 13 through 102

Figure 5. Attachment Root Mesh,
Page 1 of 2.



(b) Elements 23 through 32

Figure 5. Continued, Page 2 of 2.

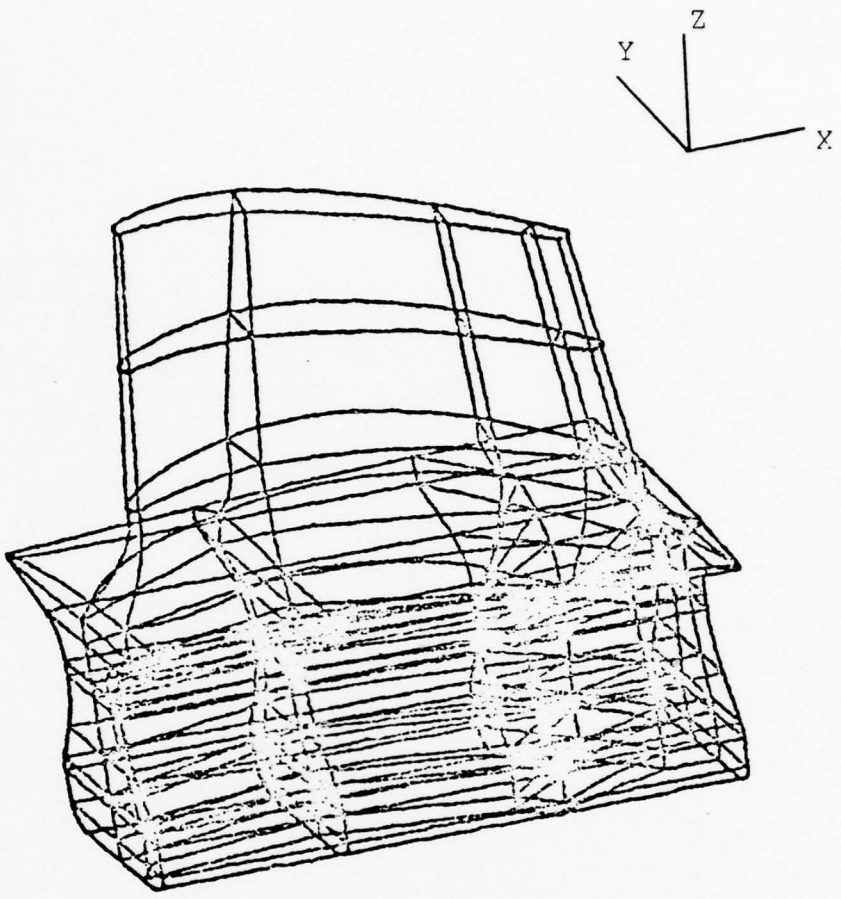


Figure 6. Completely Assembled Finite Element Analysis Mesh of Proposed Ceramic Gas Turbine Blade Design.

III. PRE-PROCESSOR DEVELOPMENT

The ADINA finite element code is a flexible, state-of-the-art code encompassing linear and non-linear, static and dynamic analyses with a choice of six types of elements and twenty material models in various combinations with element types. In this section, an explanation of the facets and capabilities of ADINA used in the blade analysis is given along with a description of the preparations that were necessary prior to execution of an analysis.

A. GENERAL DESCRIPTION OF ADINA

The brittle behavior of the hot-pressed Silicon-Nitride lends itself to the use of the linear isotropic elastic material model. Twenty node isoparametric bricks were used throughout the mesh. ADINA's use of an out-of-core solution scheme and compacted storage of matrices lends itself attractively for analysis of a large mesh which is required for the blade analysis because of the necessity of describing many different geometries.

For the chosen material model and static analysis, the equilibrium equation solved by ADINA is:

$$KU = R$$

where

K = stiffness matrix

U = displacement matrix

R = load matrix

The stiffness matrix is defined as:

$$K = \int_V B^T C B dV$$

where

B = strain-displacement transformation matrix

C = constituative stress-strain matrix

The elements of B are functions of the natural coordinates r, s, t, being derived from the isoparametric representation of displacements and the inverse of the Jacobian matrix. The integration is carried out in the natural coordinate system of reference, and dV is defined as

$$dV = \det(J)\, dr\, ds\, dt,$$

where det(J) is the determinant of the Jacobian matrix. Integration is accomplished using Gauss quadrature with the resulting matrix elements being stored in compacted form.

With the exception of gravity loading, concentrated nodal forces are the only allowed force inputs incorporated in the ADINA code implemented on the NPS computer. The rotation induced centrifugal body force needed for this analysis was obtained using an external pre-processor to be discussed in Section III-C.

In ADINA, boundary conditions constraining the structure model are imposed by eliminating global degrees of freedom of selected nodes. The real structure was constrained by a Waspaloy disk with a compliant layer interface between the ceramic contact surface and metal disk. Interpretation of

the behavior of this system of materials varies among investigators with consequent variations in modeling the boundary conditions. Without concise information on the behavior of the actual constraining mechanisms and having to limit the scope of this investigation, the tack taken was to eliminate all degrees of freedom for all nodes defining the blade contact surface.

B. MODIFICATIONS TO ADINA

The ADINA code's complex dynamic dimensioning scheme inhibits the user from making major adjustments, additions or deletions to the implemented code. Two modifications, however, were deemed important enough to implement within the code. Other problem related manipulations were implemented by external algorithms which use the ADINA input deck but do not affect the code.

Originally, ADINA came to a STOP statement when a zero or negative determinant of the Jacobian matrix was encountered. This is a valid procedure since the results of subsequent analysis would be incorrect; however, given the inexperience of this investigator and the distortions of various elements due to the requirement of producing a compatible and complete model, numerous elements were suspected of being ill-behaved, and the STOP procedure prevented efficient troubleshooting. The diagnostic output also inhibited efforts to correct model inadequacies because of a lack of identification of the offending node and element. These problems were circumvented

by deletion of the STOP statement and addition to the diagnostic the location of the offending node and element, allowing identification of all improper elements on a single trial run.

ADINA stress output consisted of three normal and three shear stresses for sixteen nodes out of a possible twenty-seven locations for each element being transmitted solely to the line-printer device. The necessity for meaningful manipulation of the massive output derived from the 682 node mesh and the desire for higher density value coverage for input into contour plotting post-processing dictated modification of the ADINA output capabilities. An additional input parameter was defined in the master control cards which allowed the user the option of requesting output values of all twenty-seven possible output locations (Figure 7). A WRITE statement was inserted to output, on a user defined file 57, all nodal stresses. Appendix A details the changes necessary to the ADINA User's Manual [Ref. 1] resulting from these modifications along with other changes from a companion investigator's contributions.

C. CENTRIFUGAL LOADING

Principal modes of loading considered for the blade were thermal, pressure and centrifugal. Given the temperature distribution, ADINA has the capacity for determining thermal gradient induced loads. External pre-processing was chosen for development of pressure and centrifugal loading. The

pressure loading pre-processor was developed by Lieutenant J. Preisel and reported in Ref. 7. A centrifugal loading algorithm was developed by this author and is described herein.

The ADINA version implemented on the Naval Postgraduate School computer accepts only concentrated nodal forces. An algorithm was developed which would calculate the nodal consistent loads equivalent to a rotation induced body force and produce an output of punched cards in a format acceptable to ADINA.

1. Mathematical Formulation

Starting with Newton's Second Law:

$$\underline{F} + \underline{I} = 0$$

$$\underline{I} = -m\,\underline{a} = -\int_V \rho dV\,\underline{a}$$

where

$\underline{F}$ = external forces

$\underline{I}$ = inertia forces

m = mass

ρ = mass density

$\underline{a}$ = acceleration

dV = differential volume

A vector of discretized consisten nodal forces (V_i) is desired such that

$$\langle V_i \rangle \{u_i\} = \langle I \rangle \{u\}$$

where

$\langle V_i \rangle$ = vector of consistent loads

$\{u_i\}$ = vector of discrete displacements

$\langle I \rangle$ = vector of inertia force components I_x, I_y, I_z

$\{u\}$ = vector of displacement function components $\langle u, v, w \rangle^T$

Using a right-hand cartesian coordinate system and isoparamatric element definitions, displacements and coordinates are discretized by

$$\{u\} = \langle h_i \rangle \{u_i\}$$
$$\{x\} = \langle h_i \rangle \{x_i\} \qquad (3)$$

where

$\langle h_i \rangle$ = vector of shape functions = f(r,s,t)

$\{x\}$ = continuum coordinates $\langle x,y,z \rangle^T$

$\{x_i\}$ = discrete nodal coordinates

The acceleration matrix is defined by

$$\underline{a} = \underline{w} \times (\underline{w} \times \underline{r}) \qquad (4)$$

where

$\underline{w}$ = angular velocity vector = $w_x\underline{i} + w_y\underline{j} + w_z\underline{k}$

$\underline{r}$ = position vector = $x\underline{i} + y\underline{j} + z\underline{k}$

$\underline{a}$ = acceleration vector = $a_x\underline{i} + a_y\underline{j} + a_z\underline{k}$

After vector algebra manipulation, one derives

$$\{a\} = [A] \{x^*\} \qquad (5)$$

where

$$A = \begin{bmatrix} -(w_y^2+w_z^2) & w_x w_y & w_x w_z \\ w_x w_y & -(w_z^2+w_x^2) & w_y w_z \\ w_x w_z & w_y w_z & -(w_x^2+w_y^2) \end{bmatrix}$$

$$\{a\} = \langle a_x, a_y, a_z \rangle^T$$

$$\{x^*\} = \langle x, y, z \rangle^T$$

Discretizing equations (1) and (5), using equation (3), and substituting into equation (2), one has

$$\langle V_i \rangle \{u_i\} = \rho \int \langle x_i \rangle \{h_i\} [A] \langle h_i \rangle \, dVol \, \{u_i\}$$

where

$$dVol = \det J \, dr \, ds \, dt$$

Simplifying and rearranging yield the following equation which was used to program the computer algorithm for development of consistent loads:

$$\{V_i\} = \rho \int \{h_i\}[A]\langle h_i \rangle \{x_i\} \quad dVol$$

2. Computer Algorithm for Program Centrifugal Load

The centrifugal load algorithm is generalized for use by any ADINA three-dimensional brick element mesh defined by eight to twenty nodes per element. A dynamic dimensioning scheme is used in order to conserve core and simplify changes dictated by the size of the user's mesh.

a. Input

Angular velocity about the three cartesian axes, mass density and an ADINA input deck are the required input for calculations in Program Centrifugal Load. In addition, several housekeeping parameters are required as defined in Appendix C.

The ADINA input deck provides node coordinates and mesh connectivity. By using the subroutine RDADIN, duplication of the considerable effort to punch and debug a large mesh is obviated. This subroutine should prove very useful for future users of ADINA who wish to manipulate mesh values.

b. Calculation of Consistent Nodal Loads

The user can select two to six Gauss point integration in the calculations of the consistent loads. Shape functions were derived from Ref. 8, which are the same used in ADINA. After calculation of loads for each element, the contributions to each node are summed in each of the three cartesian coordinate directions to yield the desired output of concentrated nodal forces. ADINA has the capability of summing concentrated nodal forces in a common direction for a given node; therefore, loads other than centrifugally induced may be input by the user without necessitating modification to Program Centrifugal Load output.

c. Output

Four options allow the user to restrict the output to what is desired for the particular problem under investigation:

(1) ICHK1. This flag allows the option for printout of the nodal coordinate data and mesh connectivity. Since this data is also output by use of the ADINA code and PSAP1, the user would normally not desire this option from Program Centrifugal Load.

(2) ICHK2. This parameter controls the option for controlling the output of consistent loads calculated for each element. The information may be useful in comparing the contributions of various elements.

(3) ICHK3. The information required by ADINA is controlled by this parameter which allows printout of the totaled consistent loads for each node for the three coordinate directions.

(4) ICHK4. This parameter gives the user the option of not punching the data cards as may be the choice for a first run.

Other output items include the total force in each of the three coordinate directions and the total number of load cards punched. The latter value is required by ADINA as parameter NLOAD on the Load Control Card described in Section IV of Ref. 1.

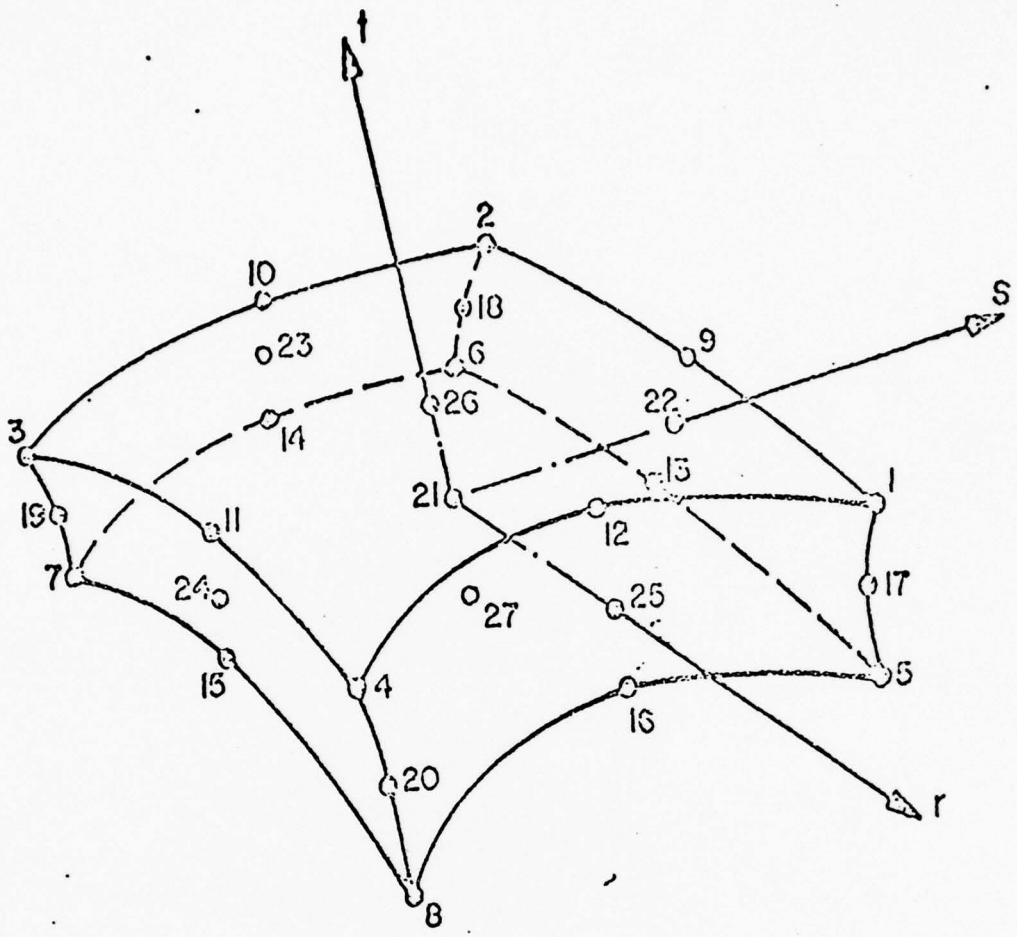


Figure 7. Stress Output Locations for ADINA Linear Static Analysis Results.

IV. PROBLEM SOLUTION

The ADINA problem solution was executed for two, three and four Gauss points used for development of the stiffness matrix. Static linear analysis was chosen for the solution method, and a material model for isotropic behavior was used. A Young's modulus of 4.0×10^7 psi was used, corresponding to the approximate value for hot-pressed Silicon-Nitride at $2500^{\circ}F$. Poissons ratio was chosen to be 0.33. Loading was accomplished using concentrated nodal forces with values obtained from the centrifugal load pre-processor for an angular velocity of 42,000 rpm about the X-axis. Table 1 summarizes the execution times for the three analyses.

OPERATION	ORDER OF INTEGRATION		
	2	3	4
INPUT PHASE	22.74	20.83	24.52
MATRICES ASSEMBLAGE	717.19	1437.83	3305.98
TRIANGULARIZATION OF STIFFNESS MATRIX	637.36	663.63	705.98
STEP BY STEP SOLUTION	110.78	111.29	110.11
TOTAL SOLUTION TIME	1549.57	2234.96	4148.07

TABLE 1. ADINA PROBLEM SOLUTION TIMES (seconds)

V. POST-PROCESSOR DEVELOPMENT

Static linear analysis using the modified version of ADINA yields three orthogonal displacements for each input node and three normal and three shear stresses at each of twenty-seven locations in a twenty node brick. The value of the stress components calculated at a given node will, in general, differ from element to element. Experience has shown that the straight average of these values give the best estimate of the real stress at that node [Ref. 8]. For problems involving brittle material, the principal stresses (particularly the maximum principal stresses) are the primary values of concern in predicting failure of the modeled component. These factors necessitated the development of post-processors to manipulate the ADINA output into the values required for analysis of results. The consequent output of these post-processors was still unmanageable from the standpoint of visual perception of the relation of the results with model geometry. Additional post-processors were, therefore, developed to yield the coordinates and connectivity of a twenty-seven node brick mesh and output of punched cards in a format applicable to the contour plotting code implemented on the Naval Postgraduate School computer.

A. PROGRAM KCONT

Prior to data manipulation, the coordinates of all nodes of the twenty-seven node brick mesh and the connectivity must be known. Program KCONT was developed to accomplish this task by using the basic isoparametric finite element model equalities:

$$x = \sum_{i=1}^{n} h_i \, x_i$$

$$y = \sum_{i=1}^{n} h_i \, y_i$$

$$z = \sum_{i=1}^{n} h_i \, z_i$$

where

x, y, z = global coordinates of any point within the element

x_i, y_i, z_i = global coordinates of the nodes defining the element

h_i = the array of shape factors as the function of the natural coordinates r, s, t.

Program KCONT first reads an ADINA input deck. It takes the input node coordinates and mesh connectivity data and computes the coordinates of the additional nodes. The twenty-seven node brick mesh connectivity is assembled and is output along with the coordinates of all nodes to the line printer and to the user defined storage files in accordance with the instructions in Appendix D.

B. PROGRAM STRESS

Program Stress reads the file defined by the ADINA code user for storage of stress results and the files storing the total connectivity and coordinate information, averages all values for each given node and determines the principal stresses from the average values. The output consists of storage of the results on user defined files and a line printer presentation. Refer to Appendix E for instructions on using Program Stress.

C. PROGRAM CONTOUR PLOT DATA

Data required by the two-dimensional iso-line contour plotting code consists of housekeeping information in the form of defined NAMELISTS, coordinate data of nodes on the analysis plane, four-node two-dimensional connectivity and input values of information to be plotted. Program Contour Plot Data was designed to define the desired analysis plane(s) and yield a punched data deck of coordinates and plotting value information. A graphics generated plot of node points and global numbers is also generated to assist the user in the formulation of the connectivity. The connectivity information must then be punched on data cards by the user and inserted into the appropriate data deck location.

Analysis planes can be defined with any of three options. The user can simply input the nodes to be used on data cards in the format 16I5. Most models, however, have surfaces of interest which are parallel to one of the three orthogonal

planes defined by the axes of the right-handed cartesian coordinate systems. Should this be the case, the user may define bounding values of a coordinate for testing the mesh for the desired nodes defining the analysis plane. If the user inputs both bounding values equal, an equality test is made in order to define the desired plane.

The program as written takes the array of plotting values from the file containing the principal stresses established by Program Stress and uses the maximum principal stress array (variable SIGMX) for plotting contours. A user may redefine the read statement (line CTRP2470 of Appendix F) in order to input the desired values for a particular problem, filling the array SIGMX with the desired plotting data. Coordinate values are read from file 58 established by Program KCONT.

The resulting punched deck of cards requires the input of connectivity and NAMELISTS &OPTION and &PICT in locations designated by Ref. 3.

D. PROGRAM CONTOUR PLOT

The contour plotting routine chosen to display stress results was developed by Gary L. Giles of the Langley Research Center for use with a variety of graphic systems including the CALCOMP plotter installed at the Naval Postgraduate School. Unfortunately, the NPS graphics software package rotates the plotting axis 90° clockwise from the original software conception of plot orientation. In order

to achieve optimum utilization of the plotting surface, the decision was made to modify the contour plot routine to utilize the NPS graphics package but yield a plot oriented with the horizontal plotting axis along the length of the paper roll as originally conceived by the CALCOMP manufacturer. In general this requires inputting to the drawing routines of NPS the negative of the desired vertical coordinate in the calling location for the x-coordinate and the positive horizontal coordinate in the calling position of the y-coordinate.

The plotting origin for the analysis plane is chosen to be the geometric center. In order to place the plot properly on the plotting surface for any set of coordinates, parameters PXORGN and PYORGN were added to NAMELIST &OPTION with default values of 0.0. Inputting the user's coordinates for the center of his analysis plane properly centers the plot on the plotting surface.

VI. RESULTS OF ADINA STRESS ANALYSIS

Stress results were analyzed using a program developed to compare the results of the two, three and four point Gauss integration analyses and plotting the iso-maximum principal stress contours for various chosen planes of analysis. Severe surface tensile stress concentrations were observed in the region immediately above the ceramic-disk contact region.

A. COMPARISON OF MAXIMUM PRINCIPAL STRESSES

Formulation of the stiffness matrix using two-point integration resulted in higher stresses caused by a lower order in integration, creating a more flexible system which concurs with finite element research [Ref. 8]. Some investigators have found that the results of reduced order integration reflect more accurately the actual component stresses because the strict mathematical development of the finite element method creates a system which is stiffer than the actual component. Insufficient experimental data, uncertainty of boundary conditions and the lack of an adequate convergence study prevent a statement of qualitative opinion of the actual stresses involved for the blade analysis; however, noting the failure rate of the few specimens which have been tested, it is probable that tensile stresses in the dovetail are higher than predicted.

Table 2 illustrates the differences between the three analyses by comparing the greatest maximum principal stress

encountered, the average of maximum principal stresses and the Euclidean norm of the differences between results for different integration order analysis.

	ORDER OF INTEGRATION		
	2	3	4
MAXIMUM PRINCIPAL STRESS	52862.39	46671.73	4674.73
AVERAGE MAX PRINCIPAL STRESS	6198.79	6100.42	6093.98
	INTEGRATION ORDER ANALYSES COMPARED		
	2-3	2-4	3-4
EUCLIDEAN NORM	122.2901	122.6712	4.7777

TABLE 2. COMPARISON OF RESULTS OF ANALYSES USING *TWO, THREE AND FOUR POINT INTEGRATION* (psi)

The maximum value occurred at node 394 which is located immediately above the contact region at level 2.9029 (Figure 8). Results from the three and four order of integration analyses showed little difference, indicating that the order of integration necessary for the "exact" evaluation of the stiffness matrix elements is being approached.

B. CONTOUR PLOT ANALYSIS

Thirty-four analysis planes were defined for contour plots. Presented herein are eight of these planes which show the regions of highest stress concentrations and the distribution of stresses in the airfoil. Figure 9 illustrates the relative position of the six plots of analysis

planes in the attachment root. The level number refers to the z-coordinate value of the nodes on that plane. The figures presented consist of an element plot, illustrating the coverage of input values to the contour plotting code, and the iso-stress plots from the second and fourth order integration analyses.

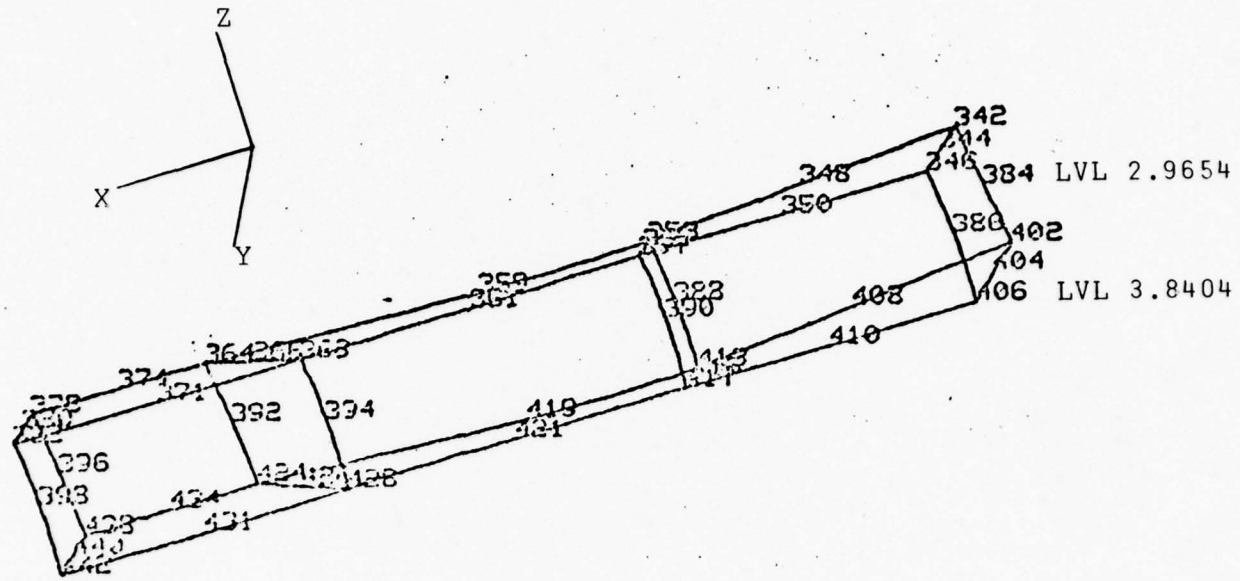
Figure 10 shows severe surface stress concentrations on both pressure and suction sides of the dovetail in the region immediately above the blade-disk contact surface. This result is consistent with other analyses of blades of similar design regardless of the boundary conditions used and loading scheme, indicating the stress distribution is principally a function of geometry. The orders of magnitude of the stress concentrations are fifty ksi for the two-point integration plot and forty-five ksi for the four-point integration plot.

Figures 11 and 12 present another view of the vertical stress distribution in dovetail. Noteworthy information from these plots is that the stress concentration is generally uniform along the length of the attachment root.

Figures 13 through 15 are plots of three horizontal surfaces in the region of high stress concentration in the dovetail.

Another region of concern in the design of a ceramic turbine blade was the fillet area of the airfoil. Figures 16 and 17 illustrate the stress distributions in the airfoil as viewed from the pressure and suction sides. Some stress

concentration does occur at the leading and trailing edges at the mid-fillet height; however, the values are minor compared to magnitudes obtained in the attachment root and relative to the strength of the material. Test results to date also indicate the adequacy of the fillet design as no failures have originated in this region except for impact initiated failure caused by flying debris upon failure of other blades.



EASTERLING-FINITE ELEMENT ANALYSIS OF A CERAMIC GAS TURBINE BLADE

Figure 8. Region of Highest Stress Concentration
Elements 60, 61 and 62.

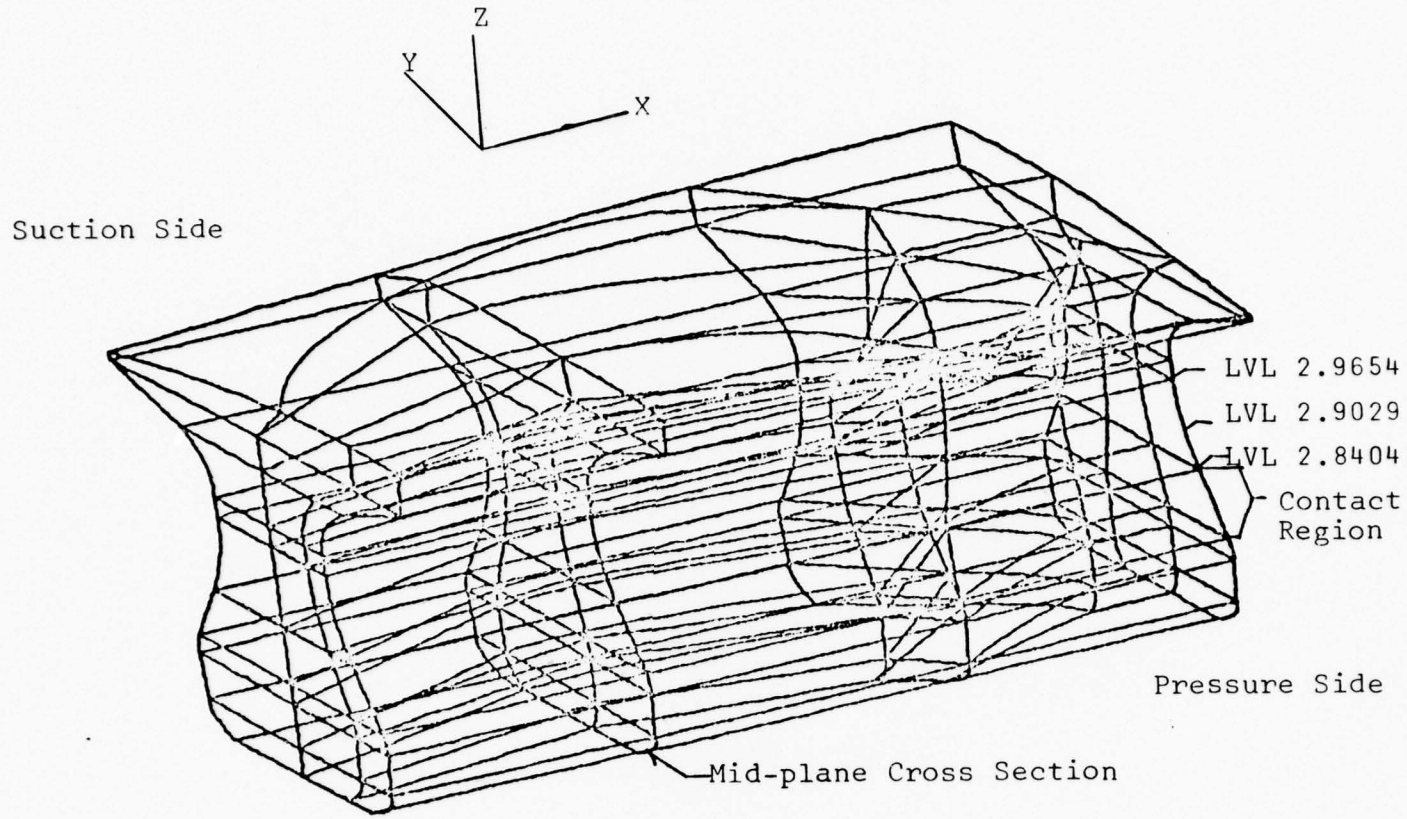
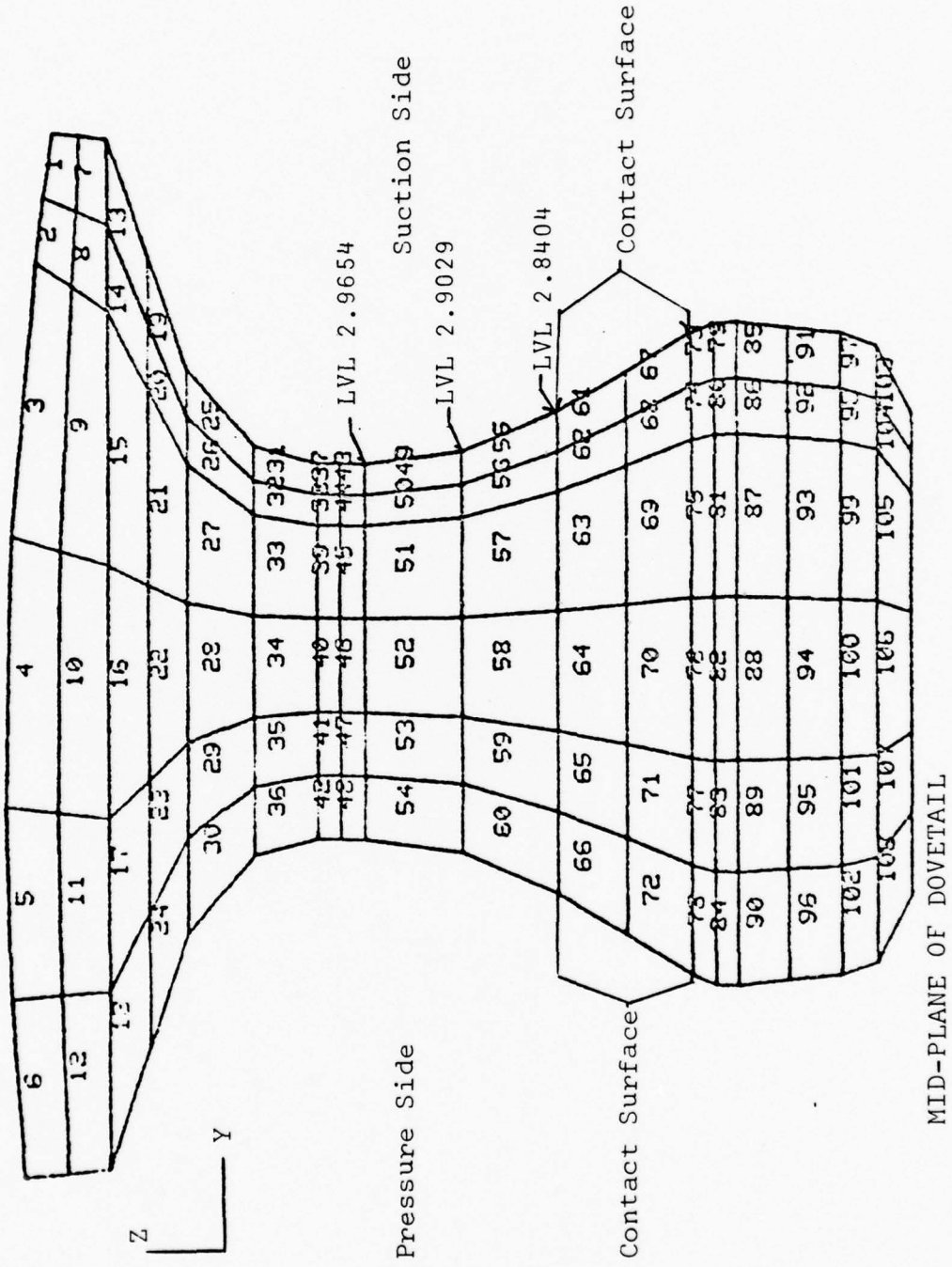
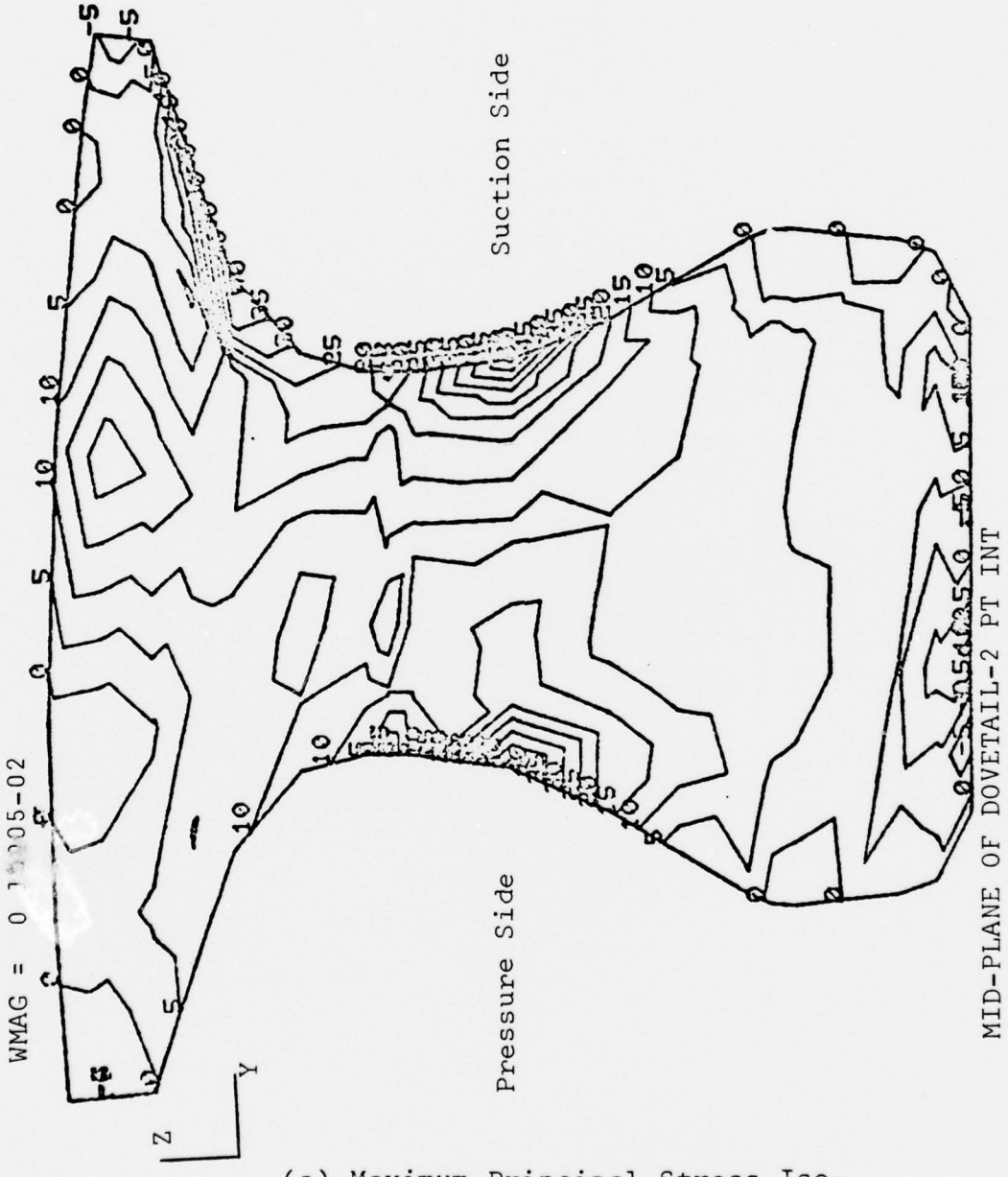


Figure 9. Attachment Root Finite Element Mesh.



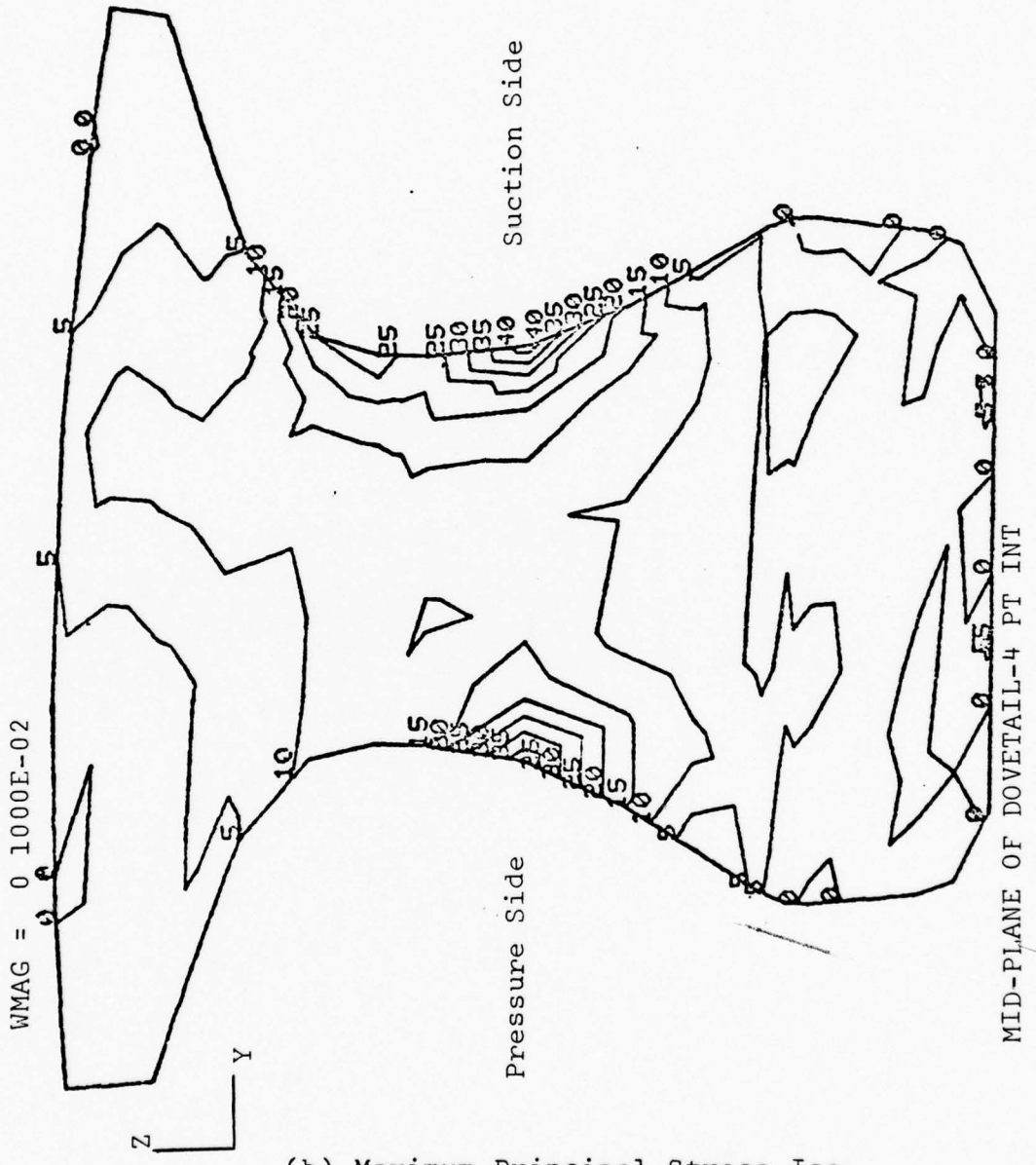
(a) 2-D Element Arrangement

Figure 10. Mid-Plane Dovetail Cross-Section,
Page 1 of 3.



(a) Maximum Principal Stress Isolines for 2-pt Order Integration (ksi)

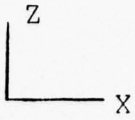
Figure 10. Continued, Page 2 of 3.



(b) Maximum Principal Stress Isolines for 4-pt Order Integration (ksi)

Figure 10. Continued, Page 3 of 3.

A: Level 2.9654
B: Level 2.9029
C: Level 2.8404
D: Contact Surface



1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24
25	26	27	28	29	30
31	32	33	34	35	36
37	38	39	40	41	42
43	44	45	46	47	48
49	50	51	52	53	54
55	56	57	58	59	60
61	62	63	64	65	66
67	68	69	70	71	72
73	74	75	76	77	78
79	80	81	82	83	84
85	86	87	88	89	90
91	92	93	94	95	96
97	98	99	100	101	102
103	104	105	106	107	108

A

D

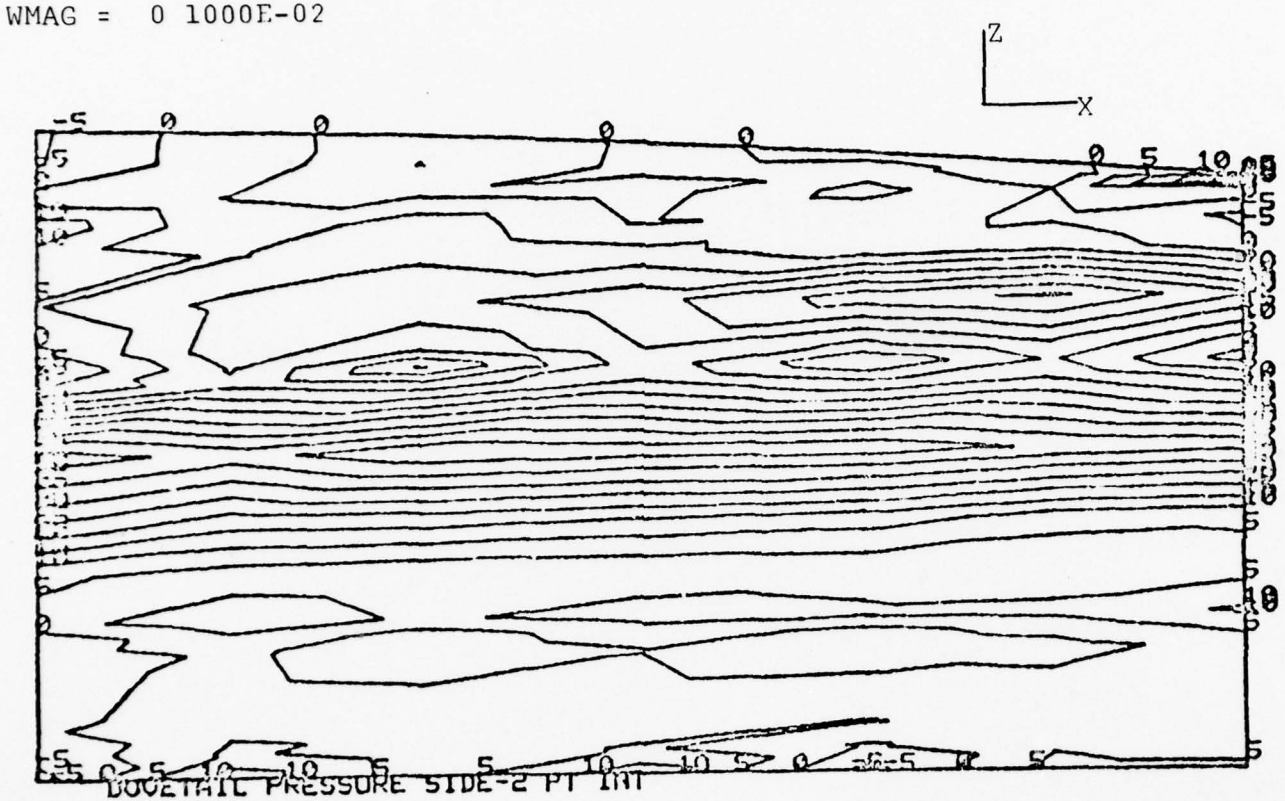
C

D

DOVETAIL PRESSURE SIDE

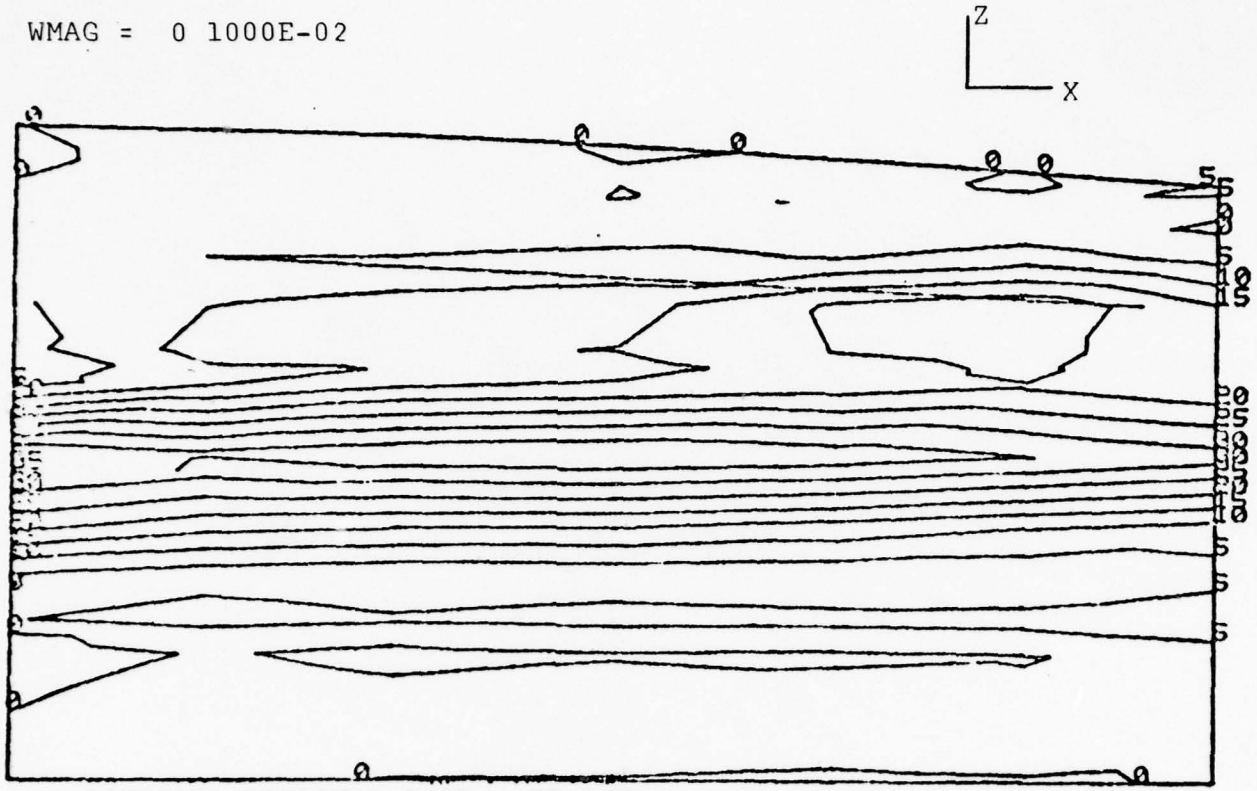
(a) 2-D Element Arrangement

Figure 11. Dovetail Pressure Side,
Page 1 of 3.



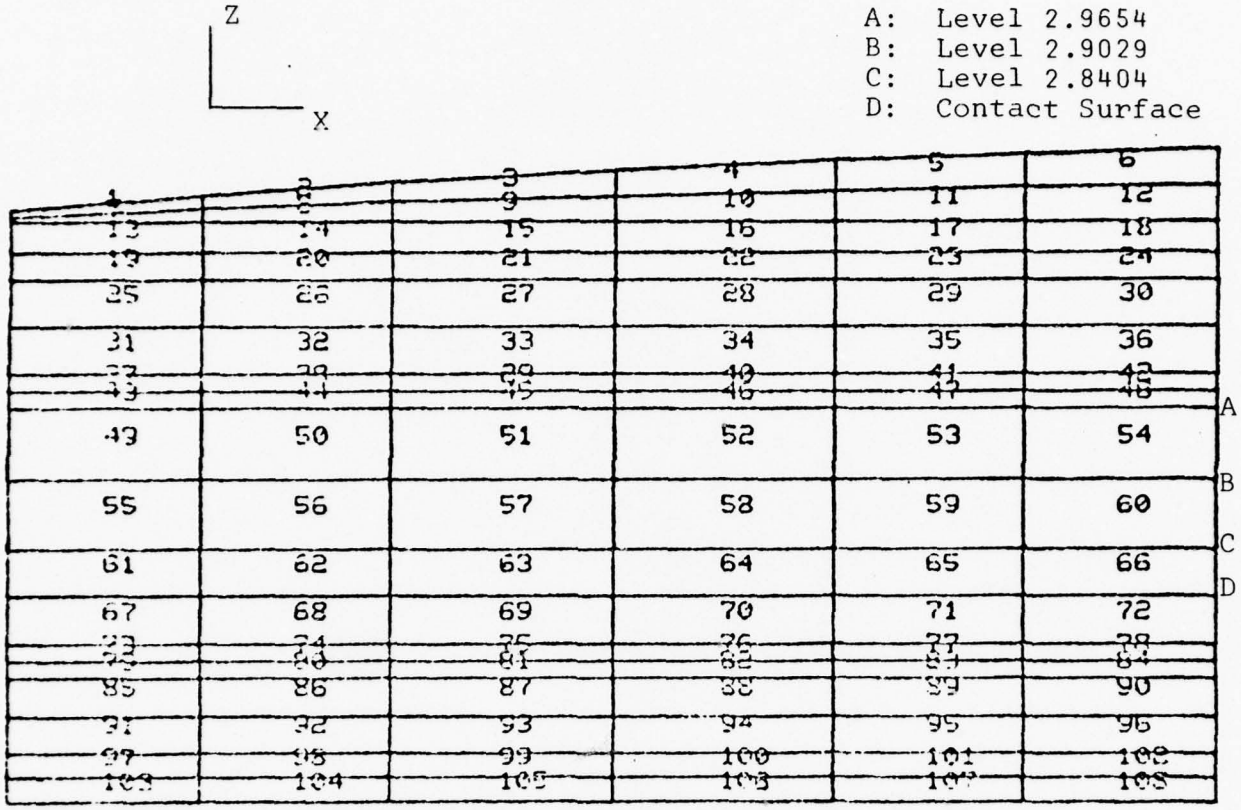
(b) Maximum Principal Stress Iso-lines
for 2-pt Order Integration (ksi)

Figure 11. Continued, Page 2 of 3.



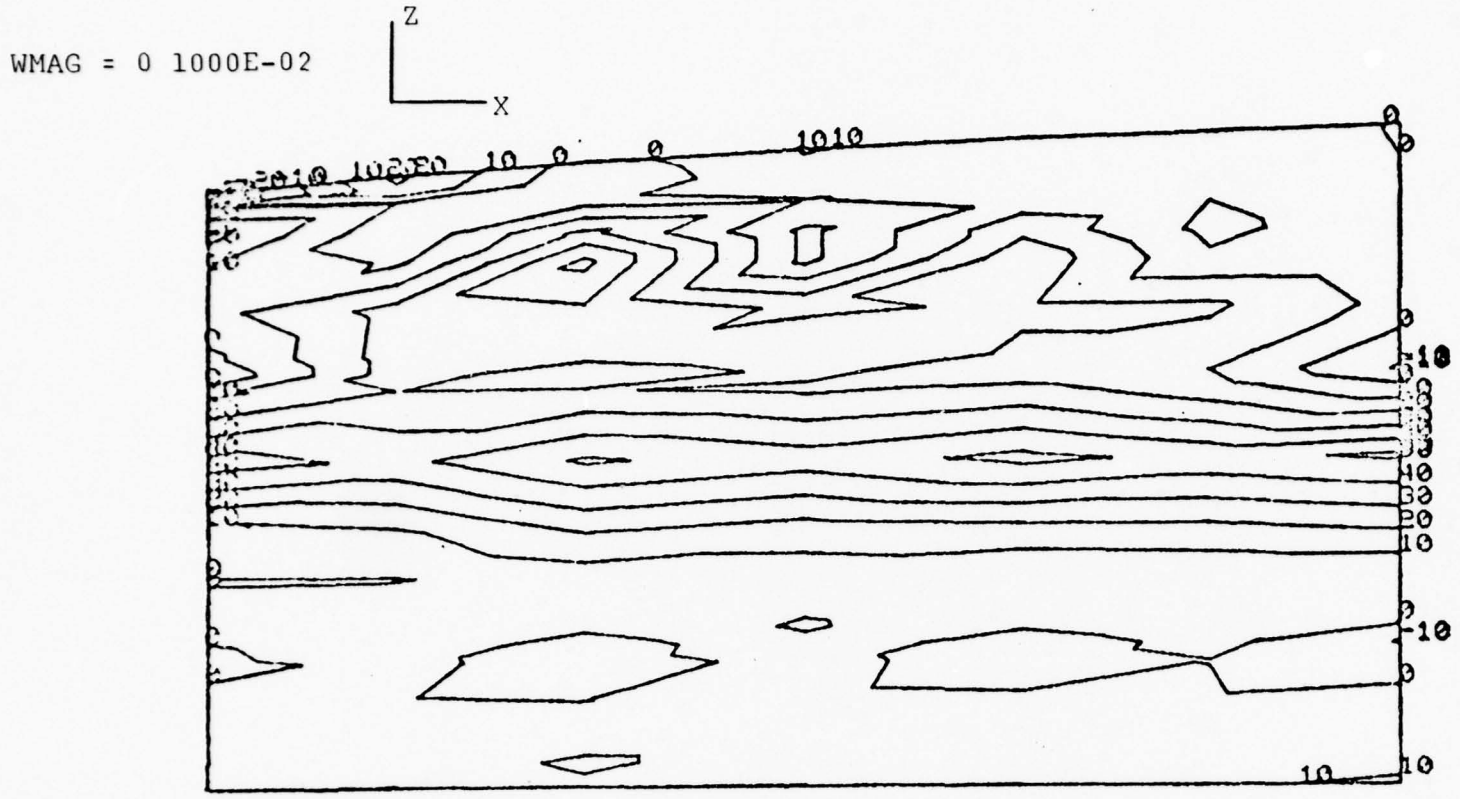
(c) Maximum Principal Stress Iso-lines
for 4-pt Integration Order (ksi)

Figure 11. Continued, Page 3 of 3.



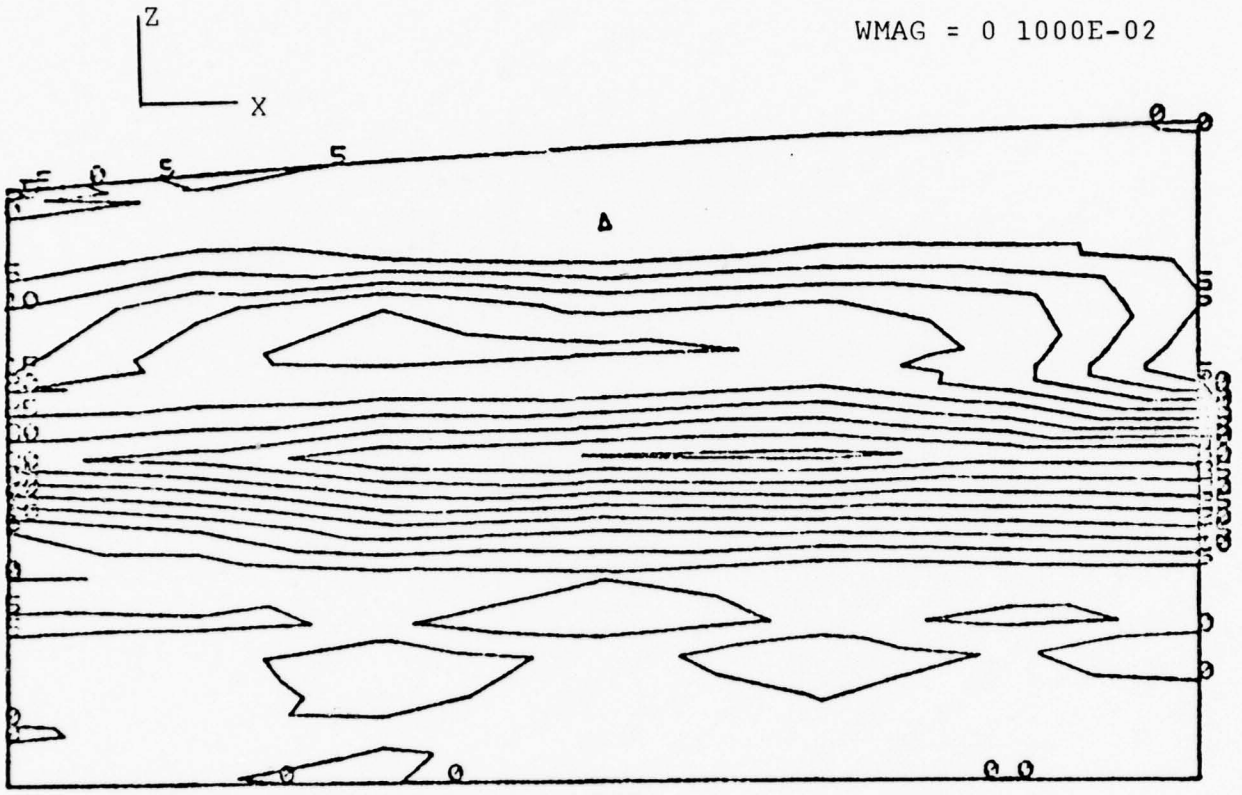
(a) 2-D Element Arrangement

Figure 12. Dovetail Suction Side,
Page 1 of 3.



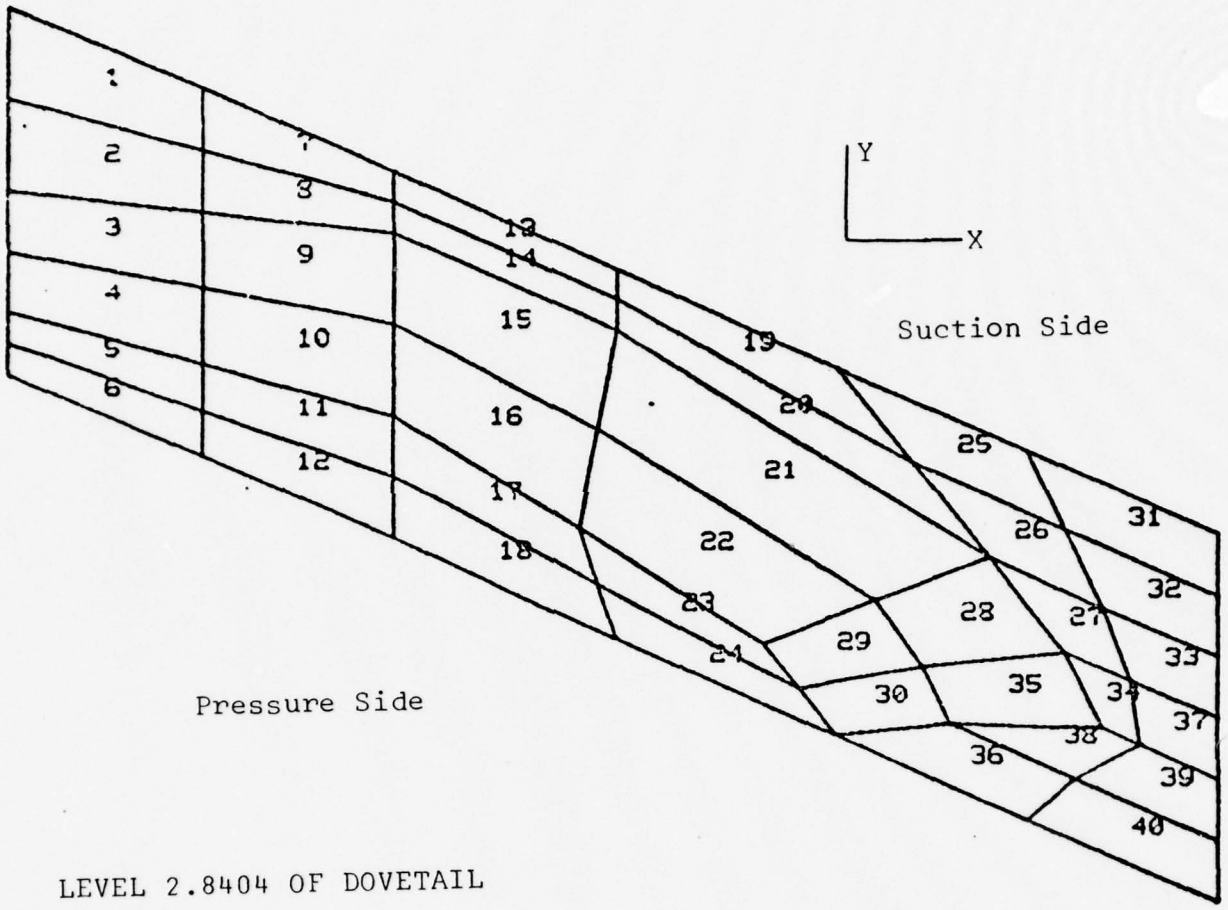
(b) Maximum Principal Stress Iso-lines
for 2-pt Integration Order (ksi)

Figure 12. Continued, Page 2 of 3.



(c) Maximum Principal Stress Iso-lines
for 4-pt Integration Order (ksi)

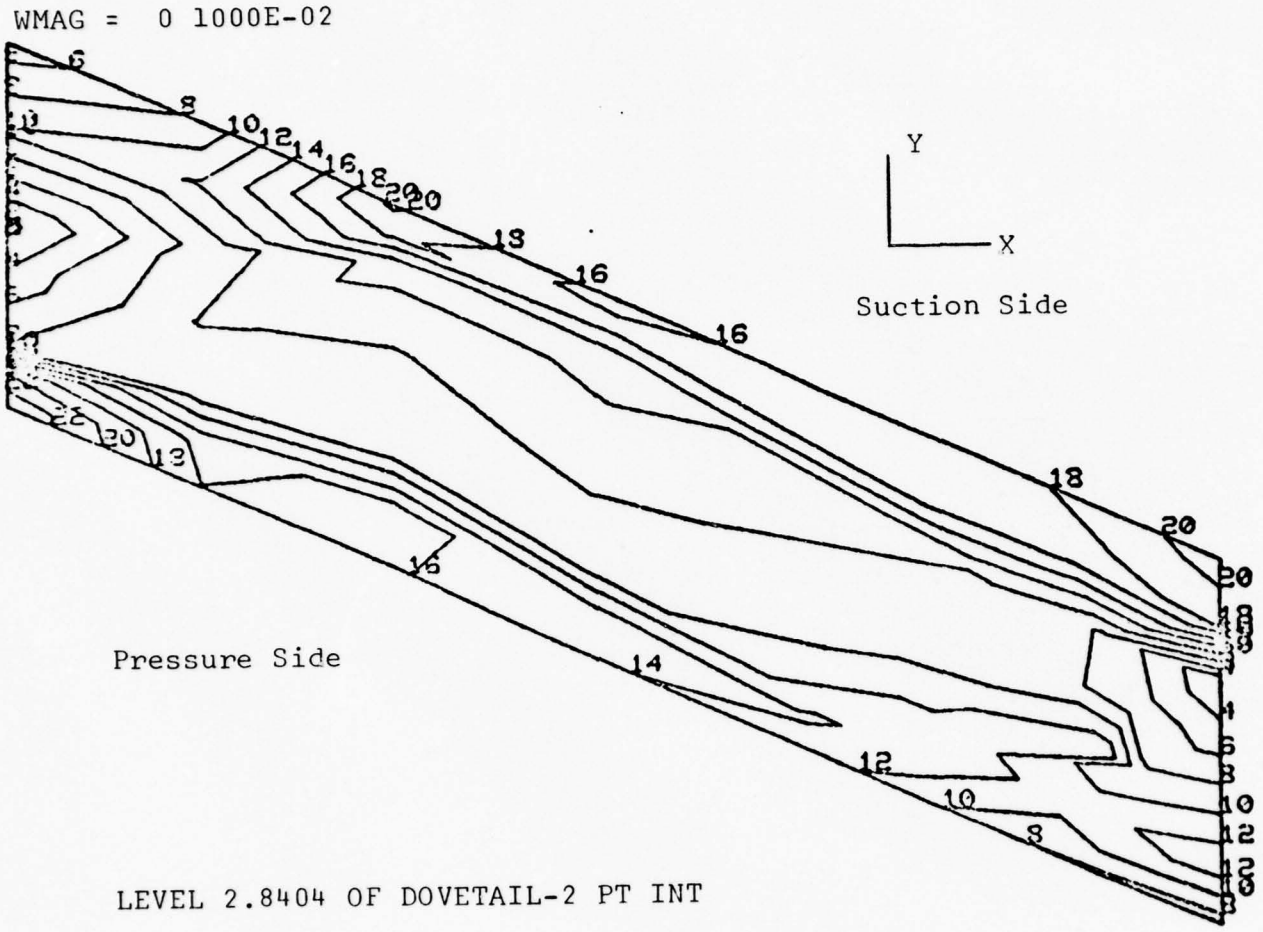
Figure 12. Continued, Page 3 of 3.



LEVEL 2.8404 OF DOVETAIL

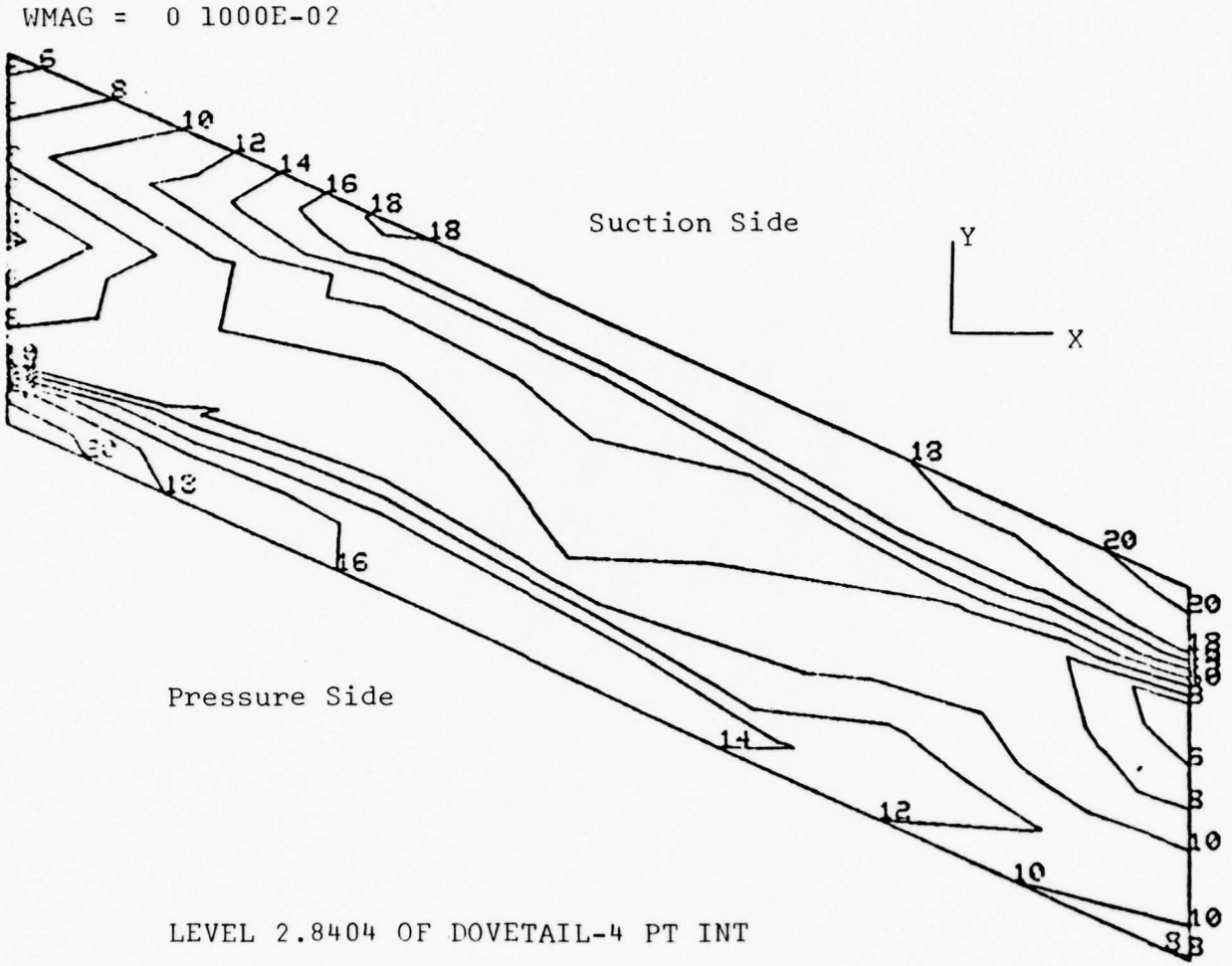
(a) 2-D Element Arrangement

Figure 13. Level 2.8404, Page 1 of 3.



(b) Maximum Principal Stress Iso-lines
for 2-pt Integration Order (ksi)

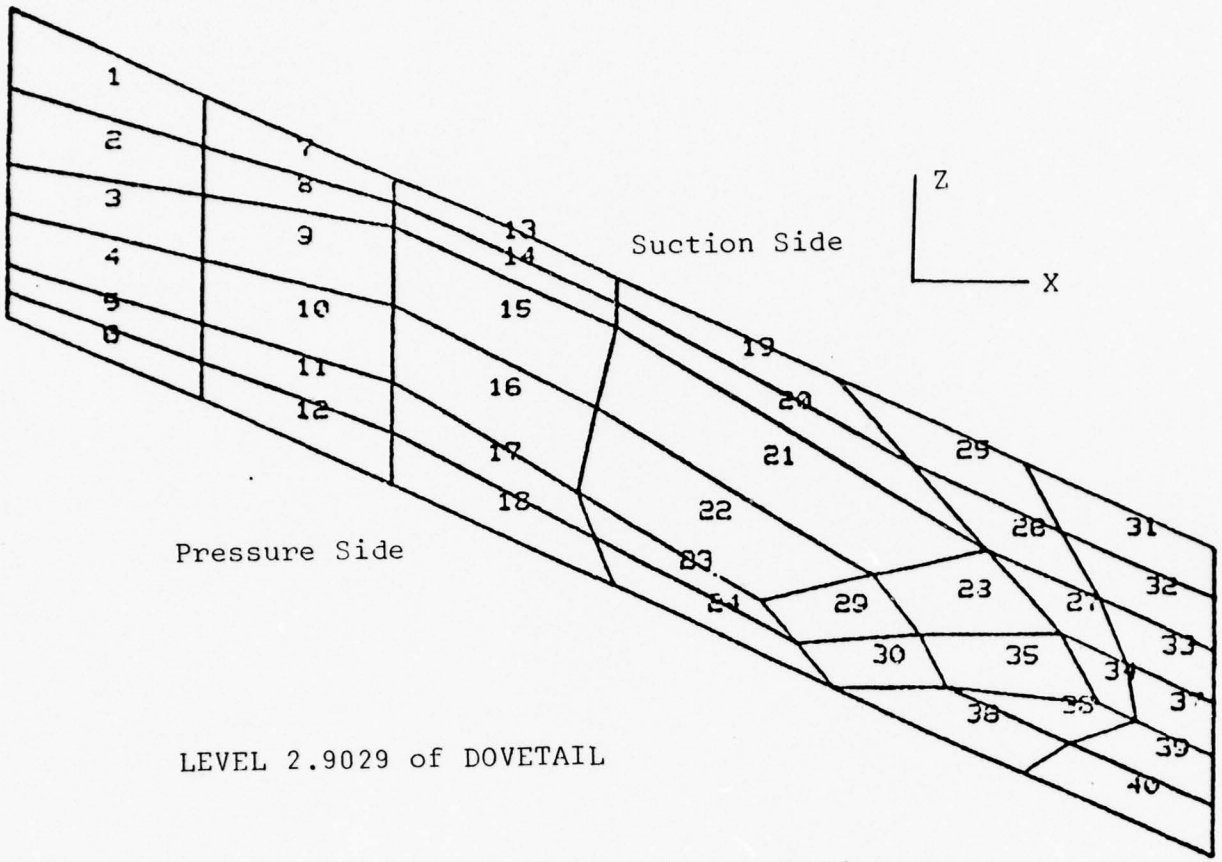
Figure 13. Continued, Page 2 of 3.



LEVEL 2.8404 OF DOVETAIL-4 PT INT

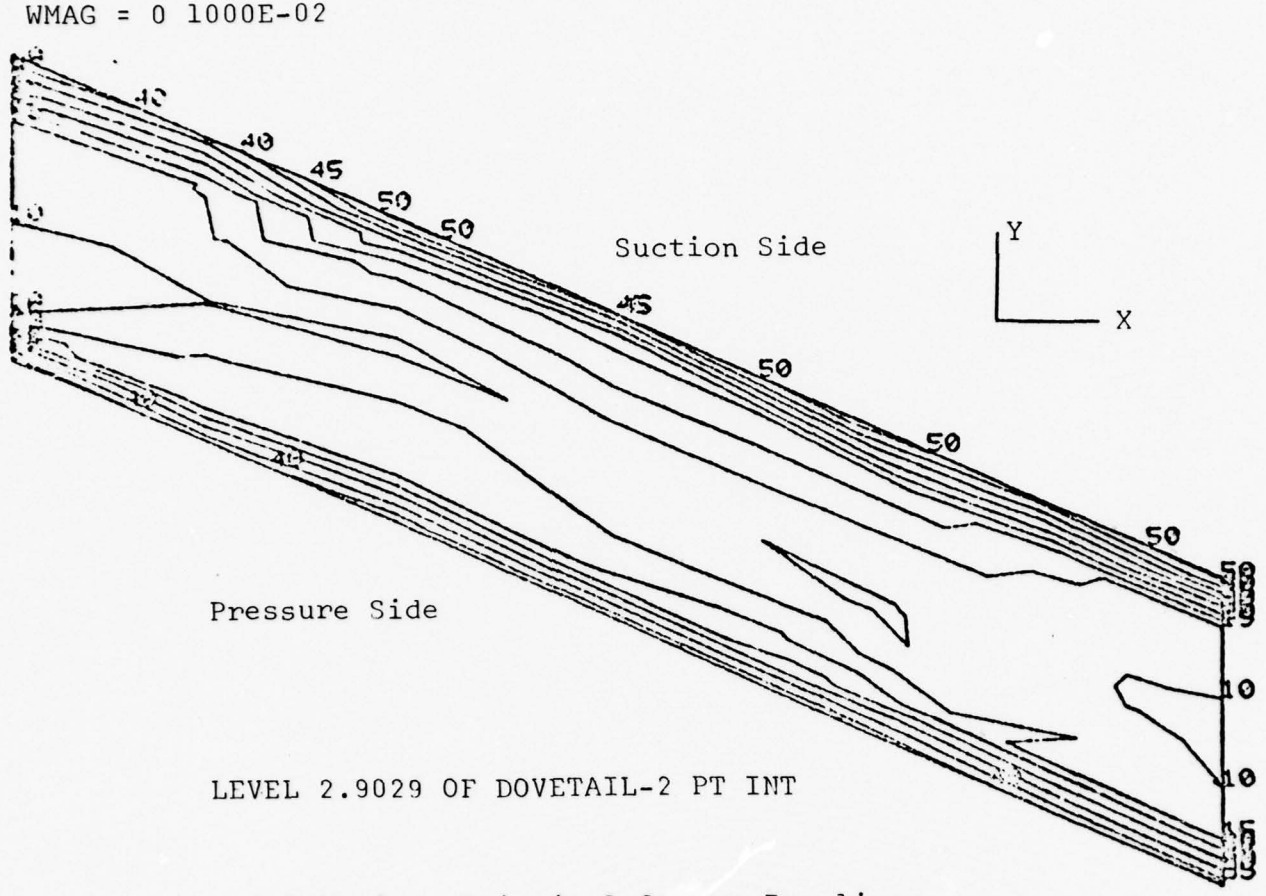
(c) Maximum Principal Stress Iso-lines
for 4-pt Integration Order (ksi)

Figure 13. Continued, Page 3 of 3.



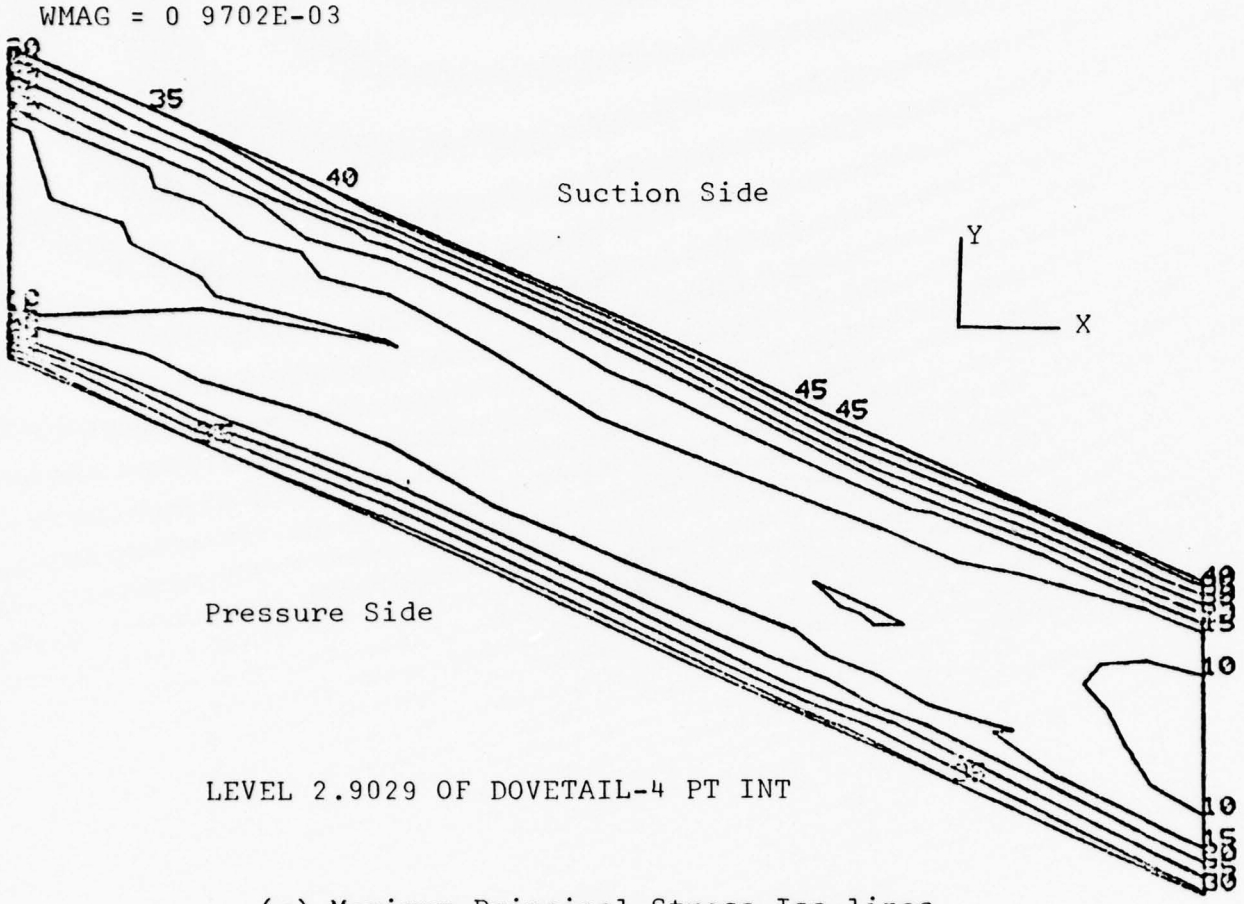
(a) 2-D Element Arrangement

Figure 14. Level 2.9029, Page 1 of 3.



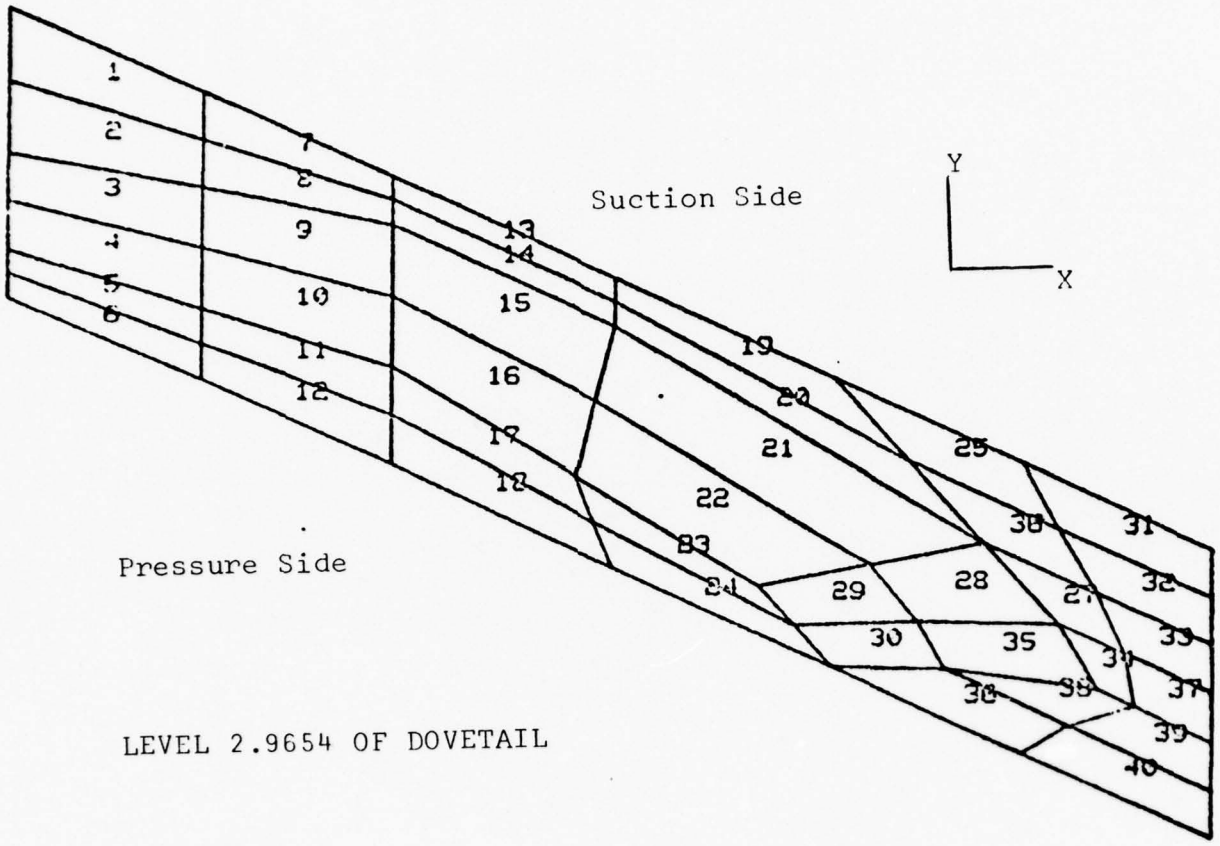
(b) Maximum Principal S[illegible]ss Iso-lines
for 2-pt Integration Order (ksi)

Figure 14. Continued, Page 2 of 3.



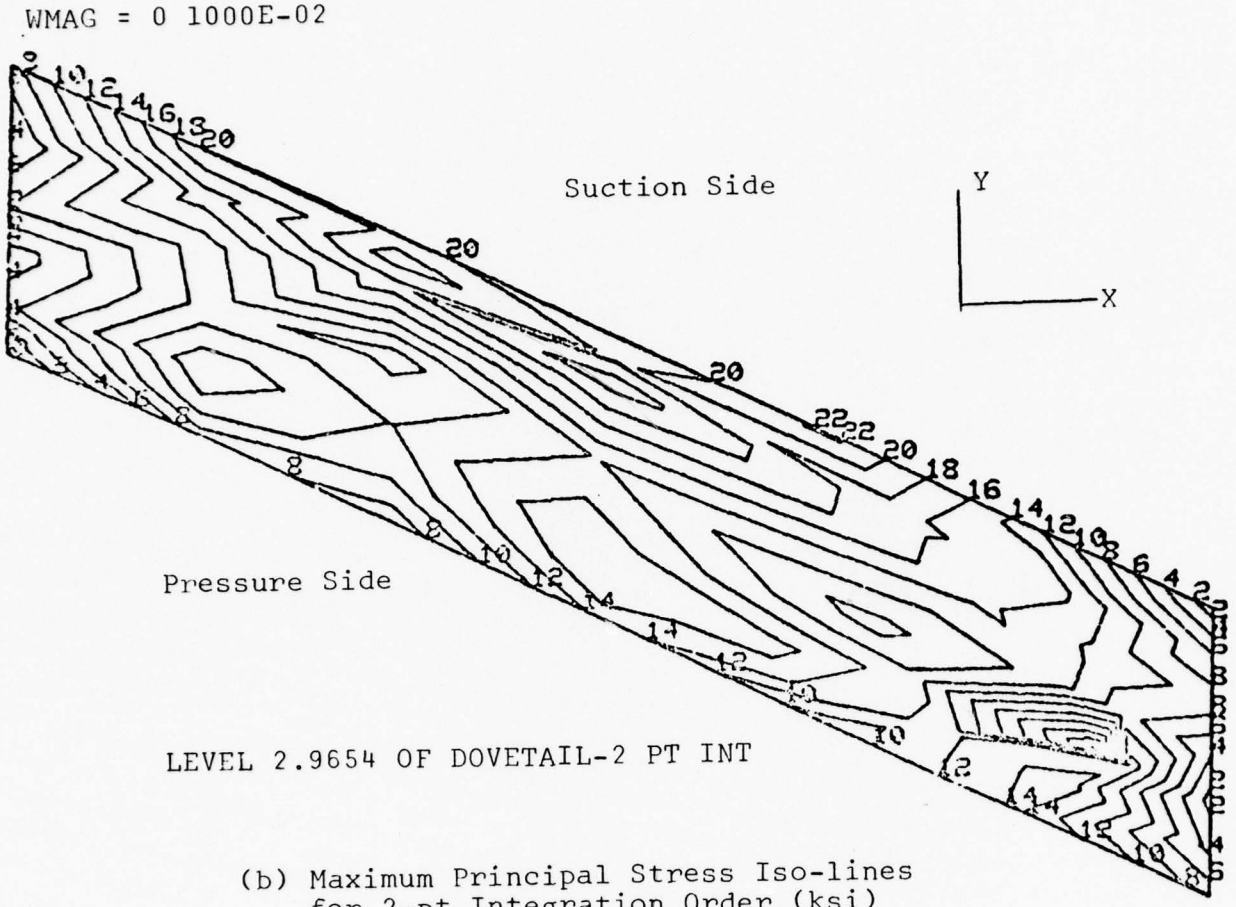
(c) Maximum Principal Stress Iso-lines
for 4-pt Integration Order (ksi)

Figure 14. Continued, Page 3 of 3.



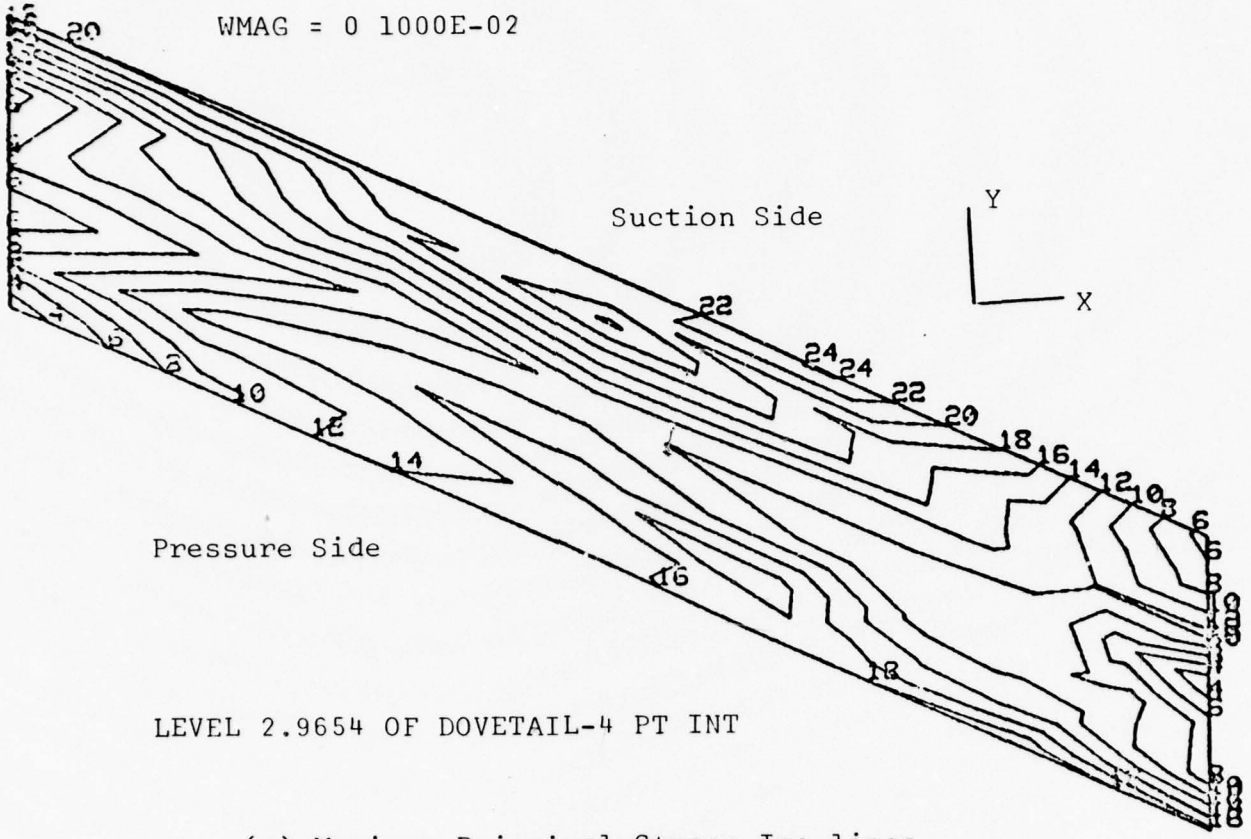
(a) 2-D Element Arrangement

Figure 15. Level 2.9651, Page 1 of 3.



(b) Maximum Principal Stress Iso-lines
for 2-pt Integration Order (ksi)

Figure 15. Continued, Page 2 of 3.



(c) Maximum Principal Stress Iso-lines
for 4-pt Integration Order (ksi)

Figure 15. Continued, Page 3 of 3.

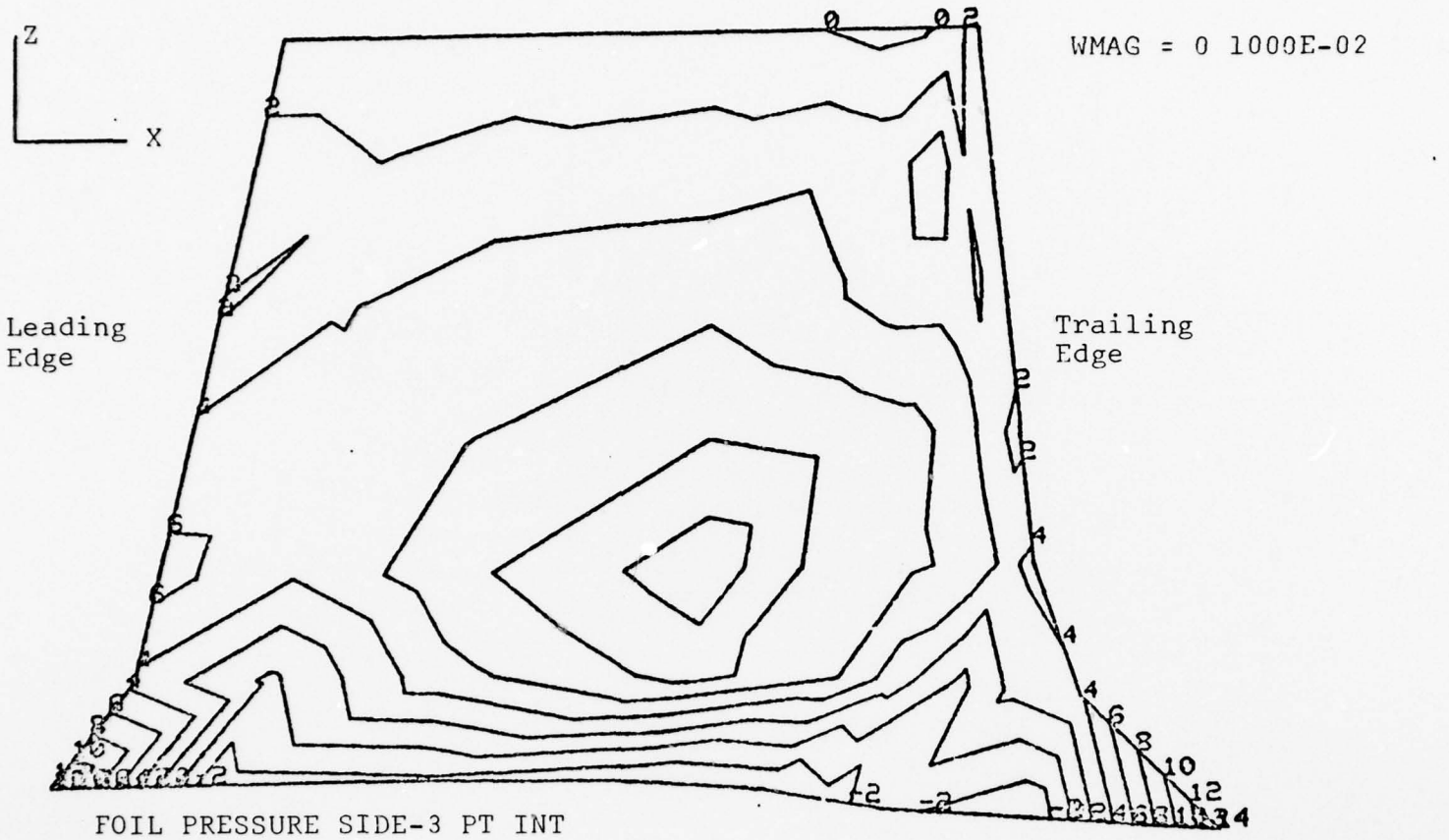


Figure 16. Maximum Principal Stress Contours for Pressure Side of Airfoil (ksi).

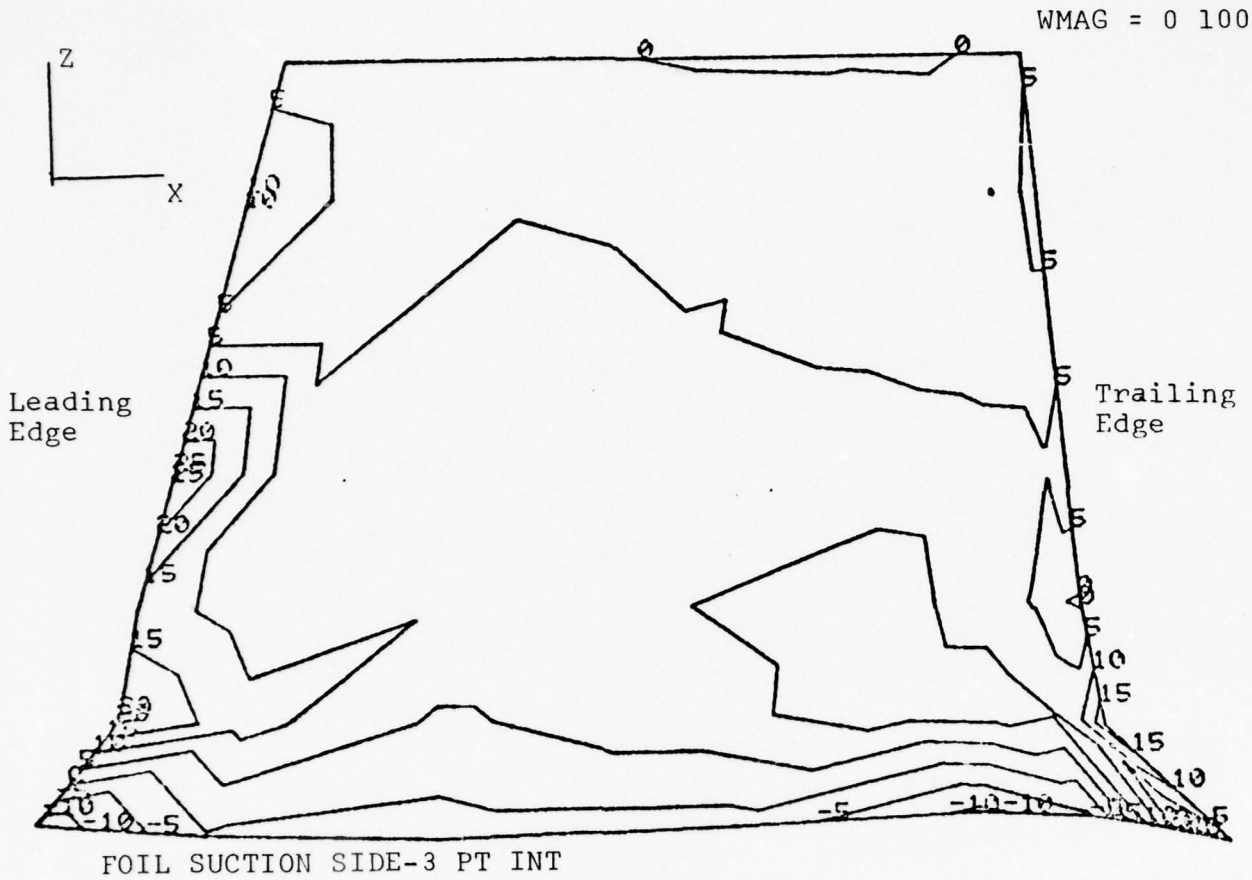


Figure 17. Maximum Principal Stress Contours for Suction Side of Airfoil (ksi).

VII. CONCLUSIONS

The time required for development of pre- and post-processors prevented a complete analysis which would have the potential for strong conclusive opinions and possible suggestions for design improvement. Software and hardware tools are, however, now implemented and identified which will allow follow-on analysis by NPS thesis students of geometric complex machine components. Despite the handicap of an inconclusive analysis, certain comments can be made concerning the results.

A. ANALYSIS RESULTS

Three other finite element analyses of ceramic turbine blade designs were reviewed by the author [Refs. 9, 10, 11]. Despite differing boundary conditions and loading schemes, a surface stress concentration persists in the region immediately above the blade-disk contact surface. This fact indicates that further research is required into the possibility of optimizing the dovetail geometry in order to spread the stresses over a greater bulk of material. If such an optimized design proves infeasible or non-existent, then the conclusion of this analysis and review indicates that hot-pressed Silicon-Nitride is unsuitable even for the limited goals of the current project. Using the four point bending strength of seventy-two ksi [Ref. 9] as a reference strength parameter, a simplistic factor of safety of 1.57 is realized. Considering the analysis did not impose

pressure and temperature gradient induced stresses, this factor of safety appears to be quite inadequate for predicting a decent probability of success.

Despite somewhat severe distortions in many of the analysis model elements, no mathematical singularities were encountered in using a reduced integration order. Further analysis using finer meshes may show that the reduced integration results are more accurate than the "exact" integration order. Should this be the case, approximately fifteen per cent higher values would be predicted than the results of "exact" integration of the stiffness matrix elements. These higher values would necessarily reduce the probability of success calculations normally used in design.

B. OPPORTUNITIES FOR FURTHER RESEARCH

The computer hardware and software at NPS, together with the groundwork laid by this thesis, allows for many avenues of follow-on research of which the following is a partial list:

1) refinement of the mesh of this analysis and convergence study of results,

2) analysis of the blade loaded under pressure and temperature gradient induced stresses,

3) optimization of attachment root design in order to alleviate stress concentrations,

4) probabilistic failure analysis using ADINA generated stresses,

5) frequency analysis of the blade,

6) investigation of appropriate boundary conditions,

7) analysis of the three material system of the blade-disk contact region.

APPENDIX A

ADDENDUM TO ADINA USER'S MANUAL, REPORT 82448-1, MIT, SEPTEMBER 1975 (Revised May 1976)

Two additional output options are available to the ADINA user at the Naval Postgraduate School besides what is described in the published user's manual. Master Control Card one, documented on page II.1, may be altered as follows:

NOTES	COLUMNS	VARIABLE	ENTRY
(a)	71-75	ITP57	Indicator for extended stress output and storage of stresses on user defined file 57.
			EQ.0; option not desired
			EQ.1; option desired
(b)	76-80	ITP58	Indicator for storage of displacements on user defined file 58.
			EQ.0; option not desired
			EQ.1; option desired

NOTES:

(a) The use of this option gives the user an output of stresses at all twenty-seven locations per element described in Section X.3 and illustrated on page X.37. Stresses are stored sequentially on user defined file 57 in the following order:

INPUT STEP

1. element number
2. integer 1 corresponding to figure X.5
3. normal stress for node in global X direction
4. normal stress for node in global Y direction
5. normal stress for node in global Z direction
6. shear stress XY
7. shear stress XZ
8. shear stress YZ

Steps 2 through 8 are repeated for the remainder of the twenty-seven nodes of the element, followed by a complete cycle for each of the remaining elements.

(b) Use of this option stores the six global displacements for each node on user defined file 58 in the following order:

INPUT STEP

1. node number
2. X direction displacement
3. Y direction displacement
4. Z direction displacement
5. X-axis rotation (if present)
6. Y-axis rotation (if present)
7. Z-axis rotation (if present)

Steps 1 through 7 are repeated for each of the input nodes. Displacements for the additional nodes for which stress results are calculated with option ITP57 are not calculated.

APPENDIX B

CONVERSION OF CALCOMP PLOTTING ROUTINES FOR USE ON A TEKTRONIX 4012 TERMINAL

The TEKTRONIX 4012 Computer Display Terminal is the most powerful interactive graphics system available to the general user at the Naval Postgraduate School. The major advantages of this unit are its speed and access to the IBM 360 computer via the CP/CMS system. A major disadvantage is there is only one terminal designated for the general user. During the final stages of preparation of this report, PSAP1 and Program Contour Plot were modified for use with the TEKTRONIX terminal in order to achieve a higher quality of plot in a timely manner than is possible with the CALCOMP system. These modifications proved quite simple and resulted in a usable plotting system. Presented in this appendix are the subroutines added to the graphics programs used by the author and a few general comments. The user should consult Refs. 12, 13, 14 and 15 for detailed information on using the TEKTRONIX unit.

The user must first determine the plotting origin of his routine and establish the limits of his plotting window using subroutine VWINDO. Caution must be used in order to ensure that the original program will properly scale the plotting values in both coordinate directions. CALCOMP PLOT statements which shift the origin must be deleted. Subroutines must then be added to the routine which are titled with CALCOMP plotting library routine names which in turn

call equivalent subroutines in the TEKTRONIX library. The following are examples used with PSAP1 and Program Contour Plot:

1) Subroutine equivalent to CALCOMP PLOTS:

```
      SUBROUTINE PLOTS
      IBAUD=480
      CALL INITT (IBAUD)
      CALL BINITT
      RETURN
      END
```

2) Subroutine equivalent to CALCOMP PLOTE:

```
      SUBROUTINE PLOTE
      IX=0
      IY=780
      CALL FINITT (IX,IY)
      RETURN
      END
```

3) Subroutine equivalent to CALCOMP LINE:

```
      SUBROUTINE LINE (Y,X,N,N1,N2)
      DIMENSION X(21), Y(21)
      CALL MOVEA (X(1),Y(1))
      DO 10 I=2,N
      CALL DRAWA (X(I),Y(I))
   10 CONTINUE
      RETURN
      END
```

4) Subroutine equivalent to CALCOMP NUMBER:

```
      SUBROUTINE NUMBER (Y,X,H,AL,TH,N)
      DIMENSION IARRAY (4)
      CALL MOVEA (X,Y)
      CALL IFORM (AL,4,IARRAY,32)
      DO 10 I=1,4
      IF (IARRAY(I).EQ.32) GO TO 10
      CALL ANCHO (IARRAY(I))
   10 CONTINUE
      RETURN
      END
```

5) Subroutine equivalent to CALCOMP SYMBOL:

```
SUBROUTINE SYMBOL (IY,IX,H,BCK,TH,N)
DIMENSION IARRAY (80),  BCK (1)
CALL CONETA (BCK,N,IARRAY)
CALL NOTATE (IX,IY,N,IARRAY)
RETURN
END
```

6) Subroutine equivalent to CALCOMP PLOT:

```
SUBROUTINE PLOT (Y,X,I)
IF (I.EQ.2) CALL DRAWA (X,Y)
IF (I.EQ.3) CALL MOVEA (X,Y)
RETURN
END
```

These subroutines were tailored for use only with PSAP1 and Program Contour Plot and are much more restrictive than the CALCOMP equivalent. For example, subroutine NUMBER defined above will only plot integers up to four digits whereas subroutine NUMBER used with the CALCOMP will plot any integer or floating point number input by the user. The subroutines do, however, provide an example of the simple modifications required and the TEKTRONIX software is available for a much higher degree of graphics sophistication.

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APPENDIX C

PROGRAM CENTRIFUGAL LOAD LISTING

```
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * CEN00010
C     *                                                                                               CEN00020
C     *  PROGRAM CENTRIFUGAL LOAD                                                                     CEN00030
C     *                                                                                               CEN00040
C     *  THIS PROGRAM READS AN ADINA INPUT DECK AND CALCULATES NODAL                                  CEN00050
C     *  CONSISTANT LOADS CAUSED BY A GIVEN ROTATION ABOUT ANY COMBI-                                 CEN00060
C     *  NATION OF RIGHT-HAND CARTESIAN COORDINATE SYSTEM AXES.                                       CEN00070
C     *  VARIOUS CHOICES OF OUTPUTS CAN BE SELECTED INCLUDING A                                       CEN00080
C     *  PUNCHED CARD DECK IN A FORMAT ACCEPTABLE TO ADINA FINITE                                     CEN00090
C     *  ELEMENT CODE FOR INPUT OF CONCENTRATED NODAL FORCES.                                         CEN00100
C     *                                                                                               CEN00110
C     *                                                                                               CEN00120
C     *  INPUT DATA DECK                                                                              CEN00130
C     *                                                                                               CEN00140
C     *  CARD 1  (FORMAT 4F10.0)                                                                      CEN00150
C     *                                                                                               CEN00160
C     *     VARIABLE     COL      REMARKS                                                            CEN00170
C     *      W1           1-10    ANGULAR VELOCITY ABOUT THE X-AXIS                                  CEN00180
C     *      W2          11-20    ANGULAR VELOCITY ABOUT THE Y-AXIS                                  CEN00190
C     *      W3          21-30    ANGULAR VELOCITY ABOUT THE Z-AXIS                                  CEN00200
C     *      RO          31-40    MASS DENSITY                                                       CEN00210
C     *                                                                                               CEN00220
C     *  CARD 2  (FORMAT 8I5)                                                                         CEN00230
C     *                                                                                               CEN00240
C     *      NUMNP        1-5     NUMBER OF NODES                                                    CEN00250
C     *      NUMEL        6-10    NUMBER OF ELEMENTS                                                 CEN00260
C     *      NGP         11-15    ORDER OF QAUSS POINT INTEGRATION (2-6)                             CEN00270
C     *      NCUR        16-20    LOAD CURVE NUMBER TO BE USED IN ADINA                              CEN00280
C     *                           IAW SECTION XII OF ADINA USERS MANUAL                              CEN00290
C     *      ICHK1       21 25    FLAG FOR PRINTOUT OF NODE COORDINATE ANDCEN00300
C     *                           MESH CONNECTIVITY DATA                                             CEN00310
C     *                             0-NO PRINTOUT                                                    CEN00320
C     *                             1-PRINTOUT                                                       CEN00330
C     *      ICHK2       26-30    FLAG FOR PRINTOUT OF CONSISTANT LOADS                              CEN00340
C     *                           BY ELEMENT                                                         CEN00350
C     *                             0-NO PRINTOUT                                                    CEN00360
C     *                             1-PRINTOUT                                                       CEN00370
C     *      ICHK3       31-35    FLAG FOR PRINTOUT OF TOTALED CONSISTANT                            CEN00380
C     *                           LOADS FOR EACH NODE                                                CEN00390
C     *                             0-NO PRINTOUT                                                    CEN00400
```

```
C      *                                1-PRINTOUT                                    CEN00410
C      *       ICHK4      36-40     FLAG FOR PUNCHED DECK OF NODE CONSISTANTCEN00420
C      *                           FORCES                                          CEN00430
C      *                             0-NO PUNCHING                                 CEN00440
C      *                             1-PUNCH LOAD DECK                             CEN00450
C      *                                                                           CEN00460
C      *   PLACE ADINA INPUT DECK HERE.  THE PORTION OF THE DECK REQUIRED CEN00470
C      *   IS FROM THE TITLE CARD TO THE LAST CONNECTIVITY CARD INCLUSIVE.CEN00480
C      *                                                                           CEN00490
C      *   A DYNAMIC DIMENSIONING SCHEME IS USED IN ORDER TO GENERALIZE THCEN00500
C      *   THE PROGRAM FOR VARIOUS MESHES.  SHOULD MORE STORAGE SPACE      CEN00510
C      *   BE REQUIRED, THE FOLLOWING DIAGNOSTIC WOULD BE OUTPUT:          CEN00520
C      *        MTOT=XXXXXX     INCREASE MTOT FOR ADDITIONAL STORAGE       CEN00530
C      *   SHOULD THIS DIAGNOSTIC OCCUR, CHANGE THE FOLLOWING TWO CARDS    CEN00540
C      *   IN THE MAIN PROGRAM:                                            CEN00550
C      *       COMMON A(XXXXXX)                                            CEN00560
C      *       MTOT=XXXXXXX                                                CEN00570
C      *   INCREASE XXXXXX TO A VALUE GREATER THAN THAT GIVEN FOR MTOT     CEN00580
C      *   BY THE DIAGNOSTIC.                                              CEN00590
C      *                                                                   CEN00600
C      *   REFERENCES:                                                     CEN00610
C      *     BATHE,KLAUS-JURGEN; ADINA(REPORT 82448-1);SEPT 1975,          CEN00620
C      *       (REVISION MAY 1976);MIT, CAMBRIDGE MASS.                    CEN00630
C      *                                                                   CEN00640
C      *     EASTERLING,L.R.;FINITE ELEMENT ANALYSIS OF A CERAMIC GAS      CEN00650
C      *       TURBINE BLADE, THESIS REPORT; NPS,MONTEREY CA. MAR 1978     CEN00660
C      *                                                                   CEN00670
C      *   WRITTEN BY:  PROF GILLES CANTIN AND L.R. EASTERLING,            CEN00680
C      *        NPS, MONTEREY CA. FEBRUARY 1978.                           CEN00690
C      *                                                                   CEN00700
C      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * CEN00710
C                                                                          CEN00720
       IMPLICIT REAL*8 (A-H,O-Z)                                           CEN00730
C                                                                          CEN00740
CCC    ************************************************************        CEN00750
CCC                                                                        CEN00760
CCC       MAIN PROGRAM TO READ ADINA DECK AND CALCULATE CONSISTANT         CEN00770
CCC       CENTRIFUCAL LOADS                                                CEN00780
CCC                                                                        CEN00790
CCC    ************************************************************        CEN00800
C                                                                          CEN00820
       COMMON A(15000)                                                     CEN00830
       COMMON/RPARA/W1,W2,W3,RO                                            CEN00840
       COMMON/IPARA/NUMNP,NUMEL,NGP,NCUR                                   CEN00850
       COMMON/CHECK/ICHK1,ICHK2,ICHK3,ICHK4                                CEN00860
       MTOT=15000                                                          CEN00870
       READ(5,1000)W1,W2,W3,RO                                             CEN00880
  1000 FORMAT(4F10.0)                                                      CEN00890
```

```
      READ(5,1001)NUMNP,NUMEL,NGP,NCUR,ICHK1,ICHK2,ICHK3,ICHK4                  CEN00900
 1001 FORMAT(8I5)                                                               CEN00910
      WRITE(6,1002)W1,W2,W3,RO                                                  CEN00920
      WRITE(6,1003)NUMNP,NUMEL,NGP                                              CEN00930
 1002 FORMAT(//5X,'ANGULAR VELOCITIES'/10X,'WX = ',G25.16/10X,'WY = ',          CEN00940
     1 G25.16/10X,'WZ = ',G25.16//5X,'DENSITY = ',G25.16/)                      CEN00950
 1003 FORMAT(//5X,'NUMBER OF NODE POINTS = ',I5//5X,'NUMBER OF                  CEN00960
     2 ELEMENT = ',I5//5X,'NUMBER OF GAUSS POINTS FOR INTERGRATION              CEN00970
     3 = ',I5/)                                                                 CEN00980
      N1=1                                                                      CEN00990
      N2=N1+60*NUMEL                                                            CEN01000
      N3=N2+NUMNP                                                               CEN01010
      N4=N3+NUMNP                                                               CEN01020
      N5=N4+NUMNP                                                               CEN01030
      N6=N5+NUMNP                                                               CEN01040
      N7=N6+NUMEL                                                               CEN01050
      N8=N7+20*NUMEL                                                            CEN01060
      NLAST=N8+3*NUMNP                                                          CEN01070
      IF(NLAST.GT.MTOT)WRITE(6,2000)NLAST                                       CEN01080
 2000 FORMAT(//5X, 'MTOT = ',I5,'    INCREASE MTOT FOR ADDITIONAL STORAGE       CEN01090
     1'//)                                                                      CEN01100
      CALL CENTF(A(N1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8))               CEN01110
      STOP                                                                      CEN01120
      END                                                                       CEN01130
      SUBROUTINE CENTF(TFVT,XPT,YPT,ZPT,NUMPT,NREL,NCONT,FORCE)                 CEN01140
C                                                                               CEN01150
CC    ************************************************************            CEN01160
C                                                                               CEN01170
C        SUBROUTINE TO COORDINATE INPUT AND OUTPUT OF                           CEN01180
C        CONSISTANT CENTRIFUGAL LOADS.                                          CEN01190
C                                                                               CEN01200
CC    ************************************************************            CEN01210
C                                                                               CEN01220
      IMPLICIT REAL*8 (A-H,O-Z)                                                 CEN01230
      COMMON/RPARA/W1,W2,W3,RO                                                  CEN01240
      COMMON/IPARA/NUMNP,NUMEL,NGP,NCUR                                         CEN01250
      COMMON/LOADS/NLOAD,NLCUR,NPTM,IDGRAV                                      CEN01260
      COMMON/CHECK/ICHK1,ICHK2,ICHK3,ICHK4                                      CEN01270
      DIMENSION XPT(1),YPT(1),ZPT(1),NUMPT(1),NREL(1)                           CEN01280
      DIMENSION TFVT(20,3,1),FORCE(3,1),NCONT(20,1)                             CEN01290
      CALL RDADIN(XPT,YPT,ZPT,NCONT,NREL,NUMPT)                                 CEN01300
   60 IF(ICHK1.EQ.0)GO TO 10                                                    CEN01310
      CALL PNTOUT(XPT,YPT,ZPT,NCONT,NREL,NUMPT)                                 CEN01320
   10 CALL TRANS(TFVT,XPT,YPT,ZPT,NCONT,NREL,NUMPT,FORCE)                       CEN01330
      RETURN                                                                    CEN01340
      END                                                                       CEN01350
      SUBROUTINE TRANS (TFVT,XPT,YPT,ZPT,NCONT,NREL,NUMPT,FORCE)                CEN01360
C                                                                               CEN01370
```

```
C     ****************************************************************   CEN01380
C                                                                          CEN01390
C        SUBROUTINE TO TRANSFER PARAMETERS FROM CENTF TO CUBAT             CEN01400
C                                                                          CEN01410
C     ****************************************************************   CEN01420
C                                                                          CEN01430
      IMPLICIT REAL*8 (A-H,O-Z)                                            CEN01440
      COMMON/RPARA/W1,W2,W3,RO                                             CEN01450
      COMMON/CHECK/ICHK1,ICHK2,ICHK3,ICHK4                                 CEN01460
      COMMON/IPARA/NUMNP,NUMEL,NGP,NCUR                                    CEN01470
      COMMON/LOADS/NLOAD,NLCUR,NPTM,IDGRAV                                 CEN01480
      DIMENSION XPT(1),YPT(1),ZPT(1),NUMPT(1),NREL(1),NCONT(20,1)          CEN01490
     1 ,TFVT(20,3,1),FORCE(3,1)                                            CEN01500
      DIMENSION FVT(20,3),NCON(20),COD(20,3)                               CEN01510
      DO 10 I=1,NUMEL                                                      CEN01520
      DO 20 J=1,20                                                         CEN01530
      NCON(J)=NCONT(J,I)                                                   CEN01540
      K=NCON(J)                                                            CEN01550
      COD(J,1)=XPT(K)                                                      CEN01560
      COD(J,2)=YPT(K)                                                      CEN01570
      COD(J,3)=ZPT(K)                                                      CEN01580
   20 CONTINUE                                                             CEN01590
      CALL CUBAT(COD,FVT,W1,W2,W3,RO,NCON,NGP,NREL(I))                     CEN01600
      DO 30 N=1,3                                                          CEN01610
      DO 40 II=1,20                                                        CEN01620
      IF(DABS(FVT(II,N)).LT.0.1D-8) GO TO 50                               CEN01630
      TFVT(II,N,I)=FVT(II,N)                                               CEN01640
      GO TO 40                                                             CEN01650
   50 TFVT(II,N,I)=0.0D0                                                   CEN01660
   40 CONTINUE                                                             CEN01670
   30 CONTINUE                                                             CEN01680
      IF(ICHK2.EQ.0)GO TO 10                                               CEN01690
      WRITE(6,100C)I                                                       CEN01700
      WRITE(6,1001)                                                        CEN01710
      DO 60 J=1,20                                                         CEN01720
      WRITE(6,1002)J,NCON(J),(FVT(J,N),N=1,3)                              CEN01730
   6C CONTINUE                                                             CEN01740
   1C CONTINUE                                                             CEN01750
  222 FORMAT(//5X,'XTOT = ',G25.16//5X,'YTOT = ',G25.16//5X,'ZTOT = ',     CEN01760
     1 G25.16/)                                                            CEN01770
      DO 444 I=1,NUMNP                                                     CEN01780
      DO 444 J=1,3                                                         CEN01790
  444 FORCE(J,I)=0.0D0                                                     CEN01800
      DO 333 I=1,NUMEL                                                     CEN01810
      DO 333 J=1,20                                                        CEN01820
      L=NCONT(J,I)                                                         CEN01830
      DO 333 K=1,3                                                         CEN01840
  333 FORCE(K,L)=FORCE(K,L)+TFVT(J,K,I)                                    CEN01850
```

```
      XTOT2=0.0D0                                                       CEN01860
      YTOT2=0.0D0                                                       CEN01870
      ZTOT2=0.0D0                                                       CEN01880
      DO 555 I=1,NUMNP                                                  CEN01890
      XTOT2=XTOT2+FORCE(1,I)                                            CEN01900
      YTOT2=YTOT2+FORCE(2,I)                                            CEN01910
  555 ZTOT2=ZTOT2+FORCE(3,I)                                            CEN01920
      IF(ICHK3.EQ.0)GO TO 888                                           CEN01930
      DO 666 I=1,NUMNP                                                  CEN01940
      WRITE(6,1006)I,(FORCE(J,I),J=1,3)                                 CEN01950
 1006 FORMAT(//4X,'NODE ',I5,2X,'FX = ',G25.16,2X,'FY = ',G25.16,2X,    CEN01960
     1 'FZ = ',G25.16)                                                  CEN01970
  666 CONTINUE                                                          CEN01980
  888 WRITE(6,222)XTOT2,YTOT2,ZTOT2                                     CEN01990
      KLOAD=0                                                           CEN02000
      IF(ICHK4.EQ.0)GO TO 999                                           CEN02010
      DO 777 I=1,NUMNP                                                  CEN02020
      DO 777 J=1,3                                                      CEN02030
      IF(DABS(FORCE(J,I)).LT.0.1D-8)GO TO 777                           CEN02040
      KLOAD=KLOAD+1                                                     CEN02050
      WRITE(7,1004)I,J,NCUR,FORCE(J,I)                                  CEN02060
  777 CONTINUE                                                          CEN02070
      WRITE(6,1003)KLOAD                                                CEN02080
 1000 FORMAT(//5X,'CONSISTANT CENTRIFUGAL LOADS FOR ELEMENT  ',I5//)    CEN02090
 1001 FORMAT(5X,'NATURAL',5X,'GLOBAL'/5X,'COORD NR',4X,'COORD NR ',7X,' CEN02100
     1 X-COMPONENT',14X,'Y-COMPONENT',14X,'Z-COMPONENT'//)              CEN02110
 1002 FORMAT('0',6X,I5,6X,I5,3G30.16)                                   CEN02120
 1003 FORMAT(//5X,'TOTAL ADDITIONAL NLOAD REQUIRED IS  ',I10/)          CEN02130
 1004 FORMAT(3I5,G25.16)                                                CEN02140
 1005 FORMAT(4I5)                                                       CEN02150
      RETURN                                                            CEN02160
      END                                                               CEN02170
      SUBROUTINE CUBAT(COD,FVT,W1,W2,W3,RO,NCON,NGP,IEL)                CEN02180
C                                                                       CEN02190
C        CUBAT FORMS THE CONSISTENT LOAD VECTOR CORRESPONDING TO THE    CEN02200
C        ANGULAR VELOCITY OF COMPONENT W1,W2,W3 ABOUT THE ORIGIN        CEN02210
C        PROF GILLES CANTIN AT THE NAVAL POSTGRDXUATE SCHOOL SEPT. 1977 CEN02220
C                                                                       CEN02230
      IMPLICIT REAL*8(A-H,O-Z)                                          CEN02240
      DIMENSION COD(20,3),FVT(20,3),DUM(20,3),GP(6,5),WF(6,5),NCON(20)  CEN02250
      DATA GP/.57735026918963D0,-.57735026918963D0,0.0D0,0.0D0,0.0D0,0.DCEN02260
     10,.77459666924148D0,0.0D0,-.77459666924148D0,0.0D0,0.0D0,0.0D0,.86CEN02270
     211363115940 5D0,0.33998104358486D0,-.33998104358486D0,-.86113631159CEN02280
     3405D0,0.0D0,0.0D0,.90617984593866D0,.53846931010568D0,0.0D0,-.5384CEN02290
     46931010568D0,-.90617984593866D0, 0.0D0,.93246951420315D0,.6612093BCEN02300
     5646626D0,.23861918608317D0,-.23861918608317D0,-.66120938646626D0,-CEN02310
     6.93246951420315D0/                                                CEN02320
      DATA WF/1.0D0,1.0D0,0.0D0,0.0D0,0.0D0,0.0D0,.555555555555556D0,.888CEN02330
```

```
     1ĘĘ888888889D0,.55555555555556D0,0.0D0,0.0D0,0.0D0,.3478548451374 5DCENO2340
     20,.6521451548625 5DC,.6521451548625 5D0,.3478548451374 5D0,C.0D0,0.0DCENO2350
     30,.2369268850561 9D0,.4786286704993 7D0,.5688ĘĘĘ888888 9D0,.4786286 70CENO2360
     449937D0,.2369268850561 9D0,0.0D0,.1713244923791 7D0,.3607615730481 4DCENO2370
     50,.4679139345726 9D0,.4679139345726 9D0,.3607615730481 4D0,.1713244 92CENO2380
     637917D0/                                                            CENO2390
      IF(NGP.LE.0.OR.NGP.GT.6) NGP=3                                      CENO2400
      ZRO =0.0D0                                                          CENO2410
      DC 100 I=1,20                                                       CENO2420
      DO 100 J=1,3                                                        CENO2430
  10C FVT(I,J) = ZRO                                                      CENO2440
      IDGP = NGP-1                                                        CENO2450
      DO 200 I=1,NGP                                                      CENO2460
      R = GP(I,IDGP)                                                      CENO2470
      WR= WF(I,IDGP)                                                      CENO2480
      DO 200 J=1,NGP                                                      CENO2490
      S = GP(J,IDGP)                                                      CENO2500
      WS= WF(J,IDGP)                                                      CENO2510
      DC 200 K=1,NGP                                                      CENO2520
      T = GP(K,IDGP)                                                      CENO2530
      WT= WF(K,IDGP)                                                      CENO2540
      WFAC = WR*WS*WT                                                     CENO2550
      CALL SHP20(R,S,T,DTJ,DUM,COD,W1,W2,W3,NCON,IEL)                     CENO2560
      DO 150 L =1,20                                                      CENO2570
      DC 150 M=1,3                                                        CENO2580
  150 FVT(L,M) = FVT(L,M) + DUM(L,M)*WFAC                                 CENO2590
  20C CCNTINUE                                                            CENO2600
      DC 300 I=1,20                                                       CENO2610
      DC 300 J=1,3                                                        CENO2620
  300 FVT(I,J)=FVT(I,J)*RO                                                CENO2630
      RETURN                                                              CENO2640
      END                                                                 CENO2650
      SUBROUTINE SHP20(R,S,T,DTJ,FVT,COD,W1,W2,W3,NCON,IEL)               CENO2660
C                                                                         CENO2670
C        UPON EXIT FROM THE PRESENT SUBROUTINE, FVT WILL CONTAIN          CENO2680
C        THE VALUES OF LOAD VECTOR ARGUMENT FVT(20,3) THAT CAN BE         CENO2690
C        USED FOR GAUSSIAN QUADRATURE                                     CENO2700
C                                                                         CENO2710
C        THE MATRIX ARGUMENT IS THE RESLLT OF THE PRODUCT OF THE          CENO2720
C        FOLLOWING MATRICES:  NT(20,3)*A(3,3)*N(3,20)*XYZ(20,3)*DETJ      CENO2730
C        WHERE THE MATRIX N(3,20) IS THE MATRIX OF SHAPE FUNCTICNS        CENO2740
C        NT(20,3) IS THE TRANSPOSE OF N(3,20), XYZ(20,3) IS THE           CENO2750
C        MATRIX OF COORDINATES OF THE NODES AND DETJ IS THE DETERMINANT   CENO2760
C        OF THE JACOBIAN MATRIX                                           CENO2770
C                                                                         CENO2780
C        R,S,T ARE THE NON DIMENSIONAL COORDINATES OF THE ELEMENT         CENO2790
C        DTJ IS THE DETERMINANT OF THE JACOBIAN MATRIX                    CENO2800
C        FVT  IS THE OUTPUT VECTOR                                        CENO2810
```

```
C         COD  IS AN INPUT ARRAY OF THE ELEMENT COCRCINATES IN THE        CEN02820
C         GLOBAL CCORDINAT SYSTEM                                        CEN02830
C         W1 IS THE COMPCNENT AF ANGULAR VELOCITY ABCUT THE AXIS X       CEN02840
C         W2 IS THE COMPCNENT AF ANGULAR VELOCITY ABCUT THE AXIS Y       CEN02850
C         W3 IS THE COMPCNENT AF ANGULAR VELOCITY ABOUT THE AXIS Z       CEN02860
C         NCON IS THE CONNECTIVITY MATRIX OF THE ELEMENT                 CEN02870
C         IEL  IS THE ELEMENT IDENTIFICATION NUMBER                      CEN02880
C                                                                        CEN02890
C         PROF. GILLES CANTIN  SEPT. 1977  NAVAL PCSTGRADUATE SCHOOL     CEN02900
C         MONTEREY CALIFCRNIA  93940                                     CEN02910
C                                                                        CEN02920
      IMPLICIT REAL*8(A-H,O-Z)                                           CEN02930
      DIMENSION COD(20,3),DNI(3,20),          EMI(20),PRCD1(3),PROD2(3)  CEN02940
      DIMENSION FVT(20,3),A(3,3),NCON(20)                                CEN02950
      REAL*8 JAC(3,3)                                                    CEN02960
      GP(BT) = 0.5DO*(1.0DO + BT)                                        CEN02970
      GM(BT) = 0.5DO*(1.0DO - BT)                                        CEN02980
      GZ(BT) = 1.CDO - BT*BT                                             CEN02990
      DP(BT) =  0.5DO+ZRC*BT                                             CEN03000
      DM(BT) = -0.5DO+ZRC*BT                                             CEN03010
      DZ(BT) = -2.0DO*BT                                                 CEN03020
      ZRO = 0.0DO                                                        CEN03030
      ONE = 1.0DO                                                        CEN03040
      TWO = 2.0DO                                                        CEN03050
      DC 100 I=1,3                                                       CEN03060
      DC 100 J=1,20                                                      CEN03070
      FVT(J,I) = ZRO                                                     CEN03080
  100 DNI(I,J) = ZRO                                                     CEN03090
      EMI( 9) = GZ(R)*GP(S)*GP(T)                                        CEN03100
      IF(NCON( 9).EQ.0) EMI( 9) = ZRO                                    CEN03110
      EMI(10) = GM(R)*GZ(S)*GP(T)                                        CEN03120
      IF(NCON(10).EQ.0) EMI(10) = ZRO                                    CEN03130
      EMI(11) = GZ(R)*GM(S)*GP(T)                                        CEN03140
      IF(NCON(11).EQ.0) EMI(11) = ZRO                                    CEN03150
      EMI(12) = GP(R)*GZ(S)*GP(T)                                        CEN03160
      IF(NCON(12).EQ.0) EMI(12) = ZRO                                    CEN03170
      EMI(13) = GZ(R)*GP(S)*GM(T)                                        CEN03180
      IF(NCON(13).EQ.0) EMI(13) = ZRO                                    CEN03190
      EMI(14) = GM(R)*GZ(S)*GM(T)                                        CEN03200
      IF(NCON(14).EQ.0) EMI(14) = ZRO                                    CEN03210
      EMI(15) = GZ(R)*GM(S)*GM(T)                                        CEN03220
      IF(NCON(15).EQ.0) EMI(15) = ZRO                                    CEN03230
      EMI(16) = GP(R)*GZ(S)*GM(T)                                        CEN03240
      IF(NCON(16).EQ.0) EMI(16) = ZRO                                    CEN03250
      EMI(17) = GP(R)*GP(S)*GZ(T)                                        CEN03260
      IF(NCON(17).EQ.0) EMI(17) = ZRO                                    CEN03270
      EMI(18) = GM(R)*GP(S)*GZ(T)                                        CEN03280
      IF(NCON(18).EQ.0) EMI(18) = ZRO                                    CEN03290
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      EMI(19) = GM(R)*GM(S)*GZ(T)                                                                                  CEN03300
      IF(NCON(19).EQ.0) EMI(19) = ZRO                                                                              CEN03310
      EMI(20) = GP(R)*GM(S)*GZ(T)                                                                                  CEN03320
      IF(NCON(20).EQ.0) EMI(20) = ZRO                                                                              CEN03330
      EMI( 1) = GP(R)*GP(S)*GP(T) - (EMI( 9) + EMI(12) + EMI(17))/TWO                                              CEN03340
      EMI( 2) = GM(R)*GP(S)*GP(T) - (EMI( 9) + EMI(10) + EMI(18))/TWO                                              CEN03350
      EMI( 3) = GM(R)*GM(S)*GP(T) - (EMI(10) + EMI(11) + EMI(19))/TWO                                              CEN03360
      EMI( 4) = GP(R)*GM(S)*GP(T) - (EMI(11) + EMI(12) + EMI(20))/TWO                                              CEN03370
      EMI( 5) = GP(R)*GP(S)*GM(T) - (EMI(13) + EMI(16) + EMI(17))/TWO                                              CEN03380
      EMI( 6) = GM(R)*GP(S)*GM(T) - (EMI(13) + EMI(14) + EMI(18))/TWO                                              CEN03290
      EMI( 7) = GM(R)*GM(S)*GM(T) - (EMI(14) + EMI(15) + EMI(19))/TWO                                              CEN03400
      EMI( 8) = GP(R)*GM(S)*GM(T) - (EMI(15) + EMI(16) + EMI(20))/TWO                                              CEN03410
      IF(NCON( 9).EQ.0) GO TO 500                                                                                  CEN03420
      DNI(1, 9) = DZ(R)*GP(S)*GP(T)                                                                                CEN03430
      DNI(2, 9) = GZ(R)*DP(S)*GP(T)                                                                                CEN03440
      DNI(3, 9) = GZ(R)*GP(S)*DP(T)                                                                                CEN03450
  500 IF(NCON(10).EQ.0) GO TO 510                                                                                  CEN03460
      DNI(1,10) = DM(R)*GZ(S)*GP(T)                                                                                CEN03470
      DNI(2,10) = GM(R)*DZ(S)*GP(T)                                                                                CEN03480
      DNI(3,10) = GM(R)*GZ(S)*DP(T)                                                                                CEN03490
  510 IF(NCON(11).EQ.0) GO TO 520                                                                                  CEN03500
      DNI(1,11) = DZ(R)*GM(S)*GP(T)                                                                                CEN03510
      DNI(2,11) = GZ(R)*DM(S)*GP(T)                                                                                CEN03520
      DNI(3,11) = GZ(R)*GM(S)*DP(T)                                                                                CEN03530
  520 IF(NCON(12).EQ.0) GO TO 530                                                                                  CEN03540
      DNI(1,12) = DP(R)*GZ(S)*GP(T)                                                                                CEN03550
      DNI(2,12) = GP(R)*DZ(S)*GP(T)                                                                                CEN03560
      DNI(3,12) = GP(R)*GZ(S)*DP(T)                                                                                CEN03570
  530 IF(NCON(13).EQ.0) GO TO 540                                                                                  CEN03580
      DNI(1,13) = DZ(R)*GP(S)*GM(T)                                                                                CEN03590
      DNI(2,13) = GZ(R)*DP(S)*GM(T)                                                                                CEN03600
      DNI(3,13) = GZ(R)*GP(S)*DM(T)                                                                                CEN03610
  540 IF(NCON(14).EQ.0) GO TO 550                                                                                  CEN03620
      DNI(1,14) = DM(R)*GZ(S)*GM(T)                                                                                CEN03630
      DNI(2,14) = GM(R)*DZ(S)*GM(T)                                                                                CEN03640
      DNI(3,14) = GM(R)*GZ(S)*DM(T)                                                                                CEN03650
  550 IF(NCON(15).EQ.0) GO TO 560                                                                                  CEN03660
      DNI(1,15) = DZ(R)*GM(S)*GM(T)                                                                                CEN03670
      DNI(2,15) = GZ(R)*DM(S)*GM(T)                                                                                CEN03680
      DNI(3,15) = GZ(R)*GM(S)*DM(T)                                                                                CEN03690
  560 IF(NCON(16).EQ.0) GO TO 570                                                                                  CEN03700
      DNI(1,16) = DP(R)*GZ(S)*GM(T)                                                                                CEN03710
      DNI(2,16) = GP(R)*DZ(S)*GM(T)                                                                                CEN03720
      DNI(3,16) = GP(R)*GZ(S)*DM(T)                                                                                CEN03730
  570 IF(NCON(17).EQ.0) GO TO 580                                                                                  CEN03740
      DNI(1,17) = DP(R)*GP(S)*GZ(T)                                                                                CEN03750
      DNI(2,17) = GP(R)*DP(S)*GZ(T)                                                                                CEN03760
      DNI(3,17) = GP(R)*GP(S)*DZ(T)                                                                                CEN03770
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580 IF(NCON(18).EQ.0) GO TO 590                                                  CEN03780
    DNI(1,18) = DM(R)*GP(S)*GZ(T)                                                CEN03790
    DNI(2,18) = GM(R)*DP(S)*GZ(T)                                                CEN03800
    DNI(3,18) = GM(R)*GP(S)*DZ(T)                                                CEN03810
590 IF(NCON(19).EQ.0) GO TO 600                                                  CEN03820
    DNI(1,19) = DM(R)*GM(S)*GZ(T)                                                CEN03830
    DNI(2,19) = GM(R)*DM(S)*GZ(T)                                                CEN03840
    DNI(3,19) = GM(R)*GM(S)*DZ(T)                                                CEN03850
600 IF(NCON(20).EQ.0) GO TO 620                                                  CEN03860
    DNI(1,20) = DP(R)*GM(S)*GZ(T)                                                CEN03870
    DNI(2,20) = GP(R)*DM(S)*GZ(T)                                                CEN03880
    DNI(3,20) = GP(R)*GM(S)*DZ(T)                                                CEN03890
620 CONTINUE                                                                     CEN03900
    DNI(1,1) = DP(R)*GP(S)*GP(T) - (DNI(1, 9)+DNI(1,12)+DNI(1,17))/TWOCEN03910
    DNI(2,1) = GP(R)*DP(S)*GP(T) - (DNI(2, 9)+DNI(2,12)+DNI(2,17))/TWOCEN03920
    DNI(3,1) = GP(R)*GP(S)*DP(T) - (DNI(3, 9)+DNI(3,12)+DNI(3,17))/TWOCEN03930
    DNI(1,2) = DM(R)*GP(S)*GP(T) - (DNI(1, 9)+DNI(1,10)+DNI(1,18))/TWOCEN03940
    DNI(2,2) = GM(R)*DP(S)*GP(T) - (DNI(2, 9)+DNI(2,10)+DNI(2,18))/TWOCEN03950
    DNI(3,2) = GM(R)*GP(S)*DP(T) - (DNI(3, 9)+DNI(3,10)+DNI(3,18))/TWOCEN03960
    DNI(1,3) = DM(R)*GM(S)*GP(T) - (DNI(1,10)+DNI(1,11)+DNI(1,19))/TWOCEN03970
    DNI(2,3) = GM(R)*DM(S)*GP(T) - (DNI(2,10)+DNI(2,11)+DNI(2,19))/TWOCEN03980
    DNI(3,3) = GM(R)*GM(S)*DP(T) - (DNI(3,10)+DNI(3,11)+DNI(3,19))/TWOCEN03990
    DNI(1,4) = DP(R)*GM(S)*GP(T) - (DNI(1,11)+DNI(1,12)+DNI(1,20))/TWOCEN04000
    DNI(2,4) = GP(R)*DM(S)*GP(T) - (DNI(2,11)+DNI(2,12)+DNI(2,20))/TWOCEN04010
    DNI(3,4) = GP(R)*GM(S)*DP(T) - (DNI(3,11)+DNI(3,12)+DNI(3,20))/TWOCEN04020
    DNI(1,5) = DP(R)*GP(S)*GM(T) - (DNI(1,13)+DNI(1,16)+DNI(1,17))/TWOCEN04030
    DNI(2,5) = GP(R)*DP(S)*GM(T) - (DNI(2,13)+DNI(2,16)+DNI(2,17))/TWOCEN04040
    DNI(3,5) = GP(R)*GP(S)*DM(T) - (DNI(3,13)+DNI(3,16)+DNI(3,17))/TWOCEN04050
    DNI(1,6) = DM(R)*GP(S)*GM(T) - (DNI(1,13)+DNI(1,14)+DNI(1,18))/TWOCEN04060
    DNI(2,6) = GM(R)*DP(S)*GM(T) - (DNI(2,13)+DNI(2,14)+DNI(2,18))/TWOCEN04070
    DNI(3,6) = GM(R)*GP(S)*DM(T) - (DNI(3,13)+DNI(3,14)+DNI(3,18))/TWOCEN04080
    DNI(1,7) = DM(R)*GM(S)*GM(T) - (DNI(1,14)+DNI(1,15)+DNI(1,19))/TWOCEN04090
    DNI(2,7) = GM(R)*DM(S)*GM(T) - (DNI(2,14)+DNI(2,15)+DNI(2,19))/TWOCEN04100
    DNI(3,7) = GM(R)*GM(S)*DM(T) - (DNI(3,14)+DNI(3,15)+DNI(3,19))/TWOCEN04110
    DNI(1,8) = DP(R)*GM(S)*GM(T) - (DNI(1,15)+DNI(1,16)+DNI(1,20))/TWOCEN04120
    DNI(2,8) = GP(R)*DM(S)*GM(T) - (DNI(2,15)+DNI(2,16)+DNI(2,20))/TWOCEN04130
    DNI(3,8) = GP(R)*GM(S)*DM(T) - (DNI(3,15)+DNI(3,16)+DNI(3,20))/TWOCEN04140
    DO 630 I=1,3                                                                 CEN04150
    DO 630 J=1,3                                                                 CEN04160
    JAC(I,J)=ZRO                                                                 CEN04170
    DO 630 K=1,20                                                                CEN04180
630 JAC(I,J) = JAC(I,J) + DNI(I,K)*CCD(K,J)                                      CEN04190
    A1 = JAC(1,1)*JAC(2,2)*JAC(3,3)                                              CEN04200
    A2 = JAC(1,2)*JAC(2,3)*JAC(3,1)                                              CEN04210
    A3 = JAC(1,3)*JAC(2,1)*JAC(3,2)                                              CEN04220
    B1 = JAC(3,1)*JAC(2,2)*JAC(1,3)                                              CEN04230
    B2 = JAC(3,2)*JAC(2,3)*JAC(1,1)                                              CEN04240
    B3 = JAC(3,3)*JAC(2,1)*JAC(1,2)                                              CEN04250
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      DTJ = A1+A2+A3 - (B1+B2+B3)                                       CEN04260
      IF(DTJ.LE.ZRO) GO TO 960                                          CEN04270
      A(1,1) = W2*W2 + W3*W3                                            CEN04280
      A(2,2) = W3*W3 + W1*W1                                            CEN04290
      A(3,3) = W1*W1 + W2*W2                                            CEN04300
      A(1,2) = -W1*W2                                                   CEN04310
      A(1,3) = -W1*W3                                                   CEN04320
      A(2,3) = -W2*W3                                                   CEN04330
      A(2,1) = A(1,2)                                                   CEN04340
      A(3,1) = A(1,3)                                                   CEN04350
      A(3,2) = A(2,3)                                                   CEN04360
      DO 700 I=1,3                                                      CEN04370
      PROD1(I)=0.0D0                                                    CEN04380
      DO 700 J=1,20                                                     CEN04390
  700 PROD1(I)=PROD1(I)+EMI(J)*COD(J,I)                                 CEN04400
      DO 800 I=1,3                                                      CEN04410
      PROD2(I)=0.0D0                                                    CEN04420
      DO 800 J=1,3                                                      CEN04430
  800 PROD2(I)=PROD2(I)+A(I,J)*PROD1(J)                                 CEN04440
      DO 900 I=1,20                                                     CEN04450
      DO 900 J=1,3                                                      CEN04460
  900 FVT(I,J)=EMI(I)*PROD2(J)                                          CEN04470
      DO 950 I=1,20                                                     CEN04480
      DO 950 J=1,3                                                      CEN04490
  950 FVT(I,J) = FVT(I,J)*DTJ                                           CEN04500
      RETURN                                                            CEN04510
  960 WRITE(6,1000)IEL,DTJ,R,S,T                                        CEN04520
 1000 FORMAT(//,5X,'ELEMENT NUMBER ',I5,' HAS A JACOBIAN DETERMINANT',/ CEN04530
     1,5X,'OF VALUE ',1G25.16,'*** EXECUTION STOPS ***'/,               CEN04540
     2 5X,' R = ',G25.16/5X,' S = ',G25.16/5X,' T = ',G25.16//)         CEN04550
      STOP                                                              CEN04560
      END                                                               CEN04570
      SUBROUTINE PNTOUT(XPT,YPT,ZPT,NCONT,NREL,NUMPT)                   CEN04580
C                                                                       CEN04590
CCC   ***************************************************************** CEN04600
CCC                                                                     CEN04610
CCC      SUBROUTINE TO PRINT OUT NODE AND ELEMENT INFORMATION           CEN04620
CCC                                                                     CEN04630
CCC   ***************************************************************** CEN04640
C                                                                       CEN04650
      IMPLICIT REAL*8 (A-H,O-Z)                                         CEN04660
      COMMON/IPARA/NUMNP,NUMEL,NGP,NCUR                                 CEN04670
      DIMENSION XPT(1),YPT(1),ZPT(1),NUMPT(1),NREL(1),NCONT(20,1)       CEN04680
C                                                                       CEN04690
CC *** FOR OUTPUT OF GEOMETRY INFORMATION                               CEN04700
C                                                                       CEN04710
      WRITE(6,16)                                                       CEN04720
   16 FORMAT(///,5X,'GRID POINT INFORMATION',///)                       CEN04730
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      WRITE(6,17)                                                       CEN04740
   17 FORMAT(5X,'RESEQUENCED',4X,'USER INPUT'/                          CEN04750
     15X,'GRID POINT',5X,'GRID POINT'/                                  CEN04760
     25X,'NUMBER',9X,'NUMBER',13X,'X',14X,'Y',14X,'Z'//)                CEN04770
      DO 30 I=1,NUMNP                                                   CEN04780
      WRITE(6,18) I,NUMPT(I),XPT(I),YPT(I),ZPT(I)                       CEN04790
   18 FORMAT(2X,I10,5X,I10,3X,3E15.4)                                   CEN04800
   30 CONTINUE                                                          CEN04810
      WRITE(6,19)                                                       CEN04820
   19 FORMAT(///,5X,'ELEMENT INFORMATION - WITH RESEQUENCED GRID POINTS CEN04830
     1'///)                                                             CEN04840
      WRITE (6,9008)                                                    CEN04850
 9008 FORMAT(1X,'RESEQUENCED',4X,'USER INPUT',25X,'GRID POINTS'/        CEN04860
     11X,'ELEMENT',8X,'ELEMENT'/                                        CEN04870
     21X,'NUMBER',9X,'NUMBER',7X,'    1    2    3    4    5    6    7  CEN04880
     3  8    9   10   11   12   13   14   15   16   17   18   19   20'//)CEN04890
      DO 40 I=1,NUMEL                                                   CEN04900
      WRITE(6,9010)I,NREL(I),(NCONT(J,I),J=1,20)                        CEN04910
 9010 FORMAT(1X,I4,11X,I4,9X,2015)                                      CEN04920
   40 CONTINUE                                                          CEN04930
  999 RETURN                                                            CEN04940
      END                                                               CEN04950
      SUBROUTINE RDADIN(XPT,YPT,ZPT,NCONT,NREL,NUMPT)                   CEN04960
C                                                                       CEN04970
CC    ****************************************************************  CEN04980
CC                                                                      CEN04990
CC       SUBROUTINE TO READ ADINA DECK.                                 CEN05000
CC                                                                      CEN05010
CC    ****************************************************************  CEN05020
C                                                                       CEN05030
      IMPLICIT REAL*8 (A-H,O-Z)                                         CEN05040
      REAL*4 TITLE(20)                                                  CEN05050
      COMMON/IPARA/NUMNP,NUMEL,NGP,NCUR                                 CEN05060
      COMMON/LOADS/NLOAD,NLCUR,NPTM,IDGRAV                              CEN05070
      DIMENSION XPT(1),YPT(1),ZPT(1),NUMPT(1),NREL(1),NCONT(20,1)       CEN05080
      DIMENSION IDOF(6),ID(6),IDOLD(6),NODE(20),NPAR(20)                CEN05090
     1 ,NP(20),INP(20)                                                  CEN05100
      DATA CTEST/'X       '/                                            CEN05110
      NCARD=0                                                           CEN05120
      READ(5,9000)(TITLE(I),I=1,20)                                     CEN05130
      WRITE(6,9011)(TITLE(I),I=1,20)                                    CEN05140
 9011 FORMAT(///5X,20A4,///)                                            CEN05150
C *** READ MASTER CONTROL CARDS                                         CEN05160
C *** NUMNP = TOTAL NUMBER OF NODE POINTS                               CEN05170
C *** NELTYP = NUMBER OF ELEMENT GROUPS                                 CEN05180
      READ(5,9001) NUMNP,(IDOF(I),I=1,6),NEGL,NEGNL,MODEX,NSTE         CEN05190
 9001 FORMAT(I5,6I1,I4,3I5)                                             CEN05200
      NELTYP=NEGL+NEGNL                                                 CEN05210
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      NNODE=NUMNP                                                        CEN05220
      READ(5,7002) IMASS,IDAMP,IMASSN,IDAMPN                             CEN05230
 7002 FORMAT(4I5)                                                        CEN05240
      READ(5,7002) IEIG                                                  CEN05250
      READ(5,7002) ISREF,NUMREF,IEQUIT,ITEMAX                            CEN05260
      READ(5,9000) DUMMY                                                 CEN05270
      READ(5,9000) DUMMY                                                 CEN05280
      READ(5,9000) DUMMY                                                 CEN05290
C *** READ OR GENERATE NODAL POINT DATA                                  CEN05300
      NOLD=0                                                             CEN05310
      NEQ=0                                                              CEN05320
   10 READ(5,9006)CT,N,(ID(I),I=1,6),XPT(N),YPT(N),ZPT(N),KN             CEN05330
 9006 FORMAT(A1,I4,1X,I4,5I5,3F10.0,I5)                                  CEN05340
C *** CHECK FOR CYLINDRICAL COORDINATES                                  CEN05350
      IF(CT.NE.CTEST) GO TO 12                                           CEN05360
          DUM=ZPT(N)/57.2958                                             CEN05370
          R=YPT(N)                                                       CEN05380
          YPT(N)=R*DCOS(ZPT(N)/57.2958DC)                                CEN05390
          ZPT(N)=R*DSIN(ZPT(N)/57.2958DC)                                CEN05400
   12 CONTINUE                                                           CEN05410
      NUMPT(N)=N                                                         CEN05420
      IF(NOLD.EQ.0) GO TO 50                                             CEN05430
C *** FOR GENERATION OF FIXED BOUNDARY CONDITIONS                        CEN05440
      DO 15 I=1,6                                                        CEN05450
      IF(IDOLD(I).EQ.-1.AND.ID(I).EQ.0) ID(I)=IDOLD(I)                   CEN05460
   15     CONTINUE                                                       CEN05470
      IF(KNOLD.EQ.0) GO TO 50                                            CEN05480
      NUM=(N-NOLD)/KNOLD                                                 CEN05490
      NUMN=NUM-1                                                         CEN05500
      IF(NUMN.LT.1) GO TO 50                                             CEN05510
C *** TO COUNT DOFS TO DETERMINE NUMBER OF IC CARDS                      CEN05520
      DO 20 I=1,6                                                        CEN05530
          IF(IDOF(I).EQ.0.AND.IDOLD(I).EQ.0) NEQ=NEQ+NUMN                CEN05540
   20 CONTINUE                                                           CEN05550
      DX=(XPT(N)-XPT(NOLD))/NUM                                          CEN05560
      IF(CT.NE.CTEST) GO TO 21                                           CEN05570
      ROLD=YPT(NOLD)/DCOS(DUMOLD)                                        CEN05580
      RNEW=YPT(N)/DCOS(DUM)                                              CEN05590
      DR=(RNEW-ROLD)/NUM                                                 CEN05600
      DT=(DUM-DUMOLD)/NUM                                                CEN05610
      GO TO 22                                                           CEN05620
   21 CONTINUE                                                           CEN05630
      DY=(YPT(N)-YPT(NOLD))/NUM                                          CEN05640
      DZ=(ZPT(N)-ZPT(NOLD))/NUM                                          CEN05650
   22 CONTINUE                                                           CEN05660
      K=NOLD                                                             CEN05670
      DO 30 J=1,NUMN                                                     CEN05680
         KK=K                                                            CEN05690
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            K=K+KNOLD                                                          CEN05700
            XPT(K)=XPT(KK)+DX                                                  CEN05710
             IF(CT.NE.CTEST) GO TO 26                                          CEN05720
             ROLD=ROLD+DR                                                      CEN05730
             DUMOLD=DUMOLD+DT                                                  CEN05740
             YPT(K)=ROLD*DCOS(DUMOLD)                                          CEN05750
             ZPT(K)=ROLD*DSIN(DUMOLD)                                          CEN05760
             GO TO 28                                                          CEN05770
      26     CONTINUE                                                          CEN05780
            YPT(K)=YPT(KK)+DY                                                  CEN05790
            ZPT(K)=ZPT(KK)+DZ                                                  CEN05800
      28     CONTINUE                                                          CEN05810
            NUMPT(K)=K                                                         CEN05820
      30    CONTINUE                                                          CEN05830
      50  NOLD=N                                                               CEN05840
          KNOLD=KN                                                             CEN05850
          DUMOLD=DUM                                                           CEN05860
C ***     TO COUNT DOFS TO DETERMINE NUMBER OF IC CARDS                        CEN05870
          DO 55 I=1,6                                                          CEN05880
             IF(IDOF(I).EQ.0.AND.ID(I).EQ.0) NEQ=NEQ+1                         CEN05890
             IDOLD(I)=ID(I)                                                    CEN05900
      55    CONTINUE                                                          CEN05910
          IF(N.NE.NUMNP) GO TO 10                                              CEN05920
C ***     READ LOAD CONTROL CARDS                                              CEN05930
          READ(5,9012)NLOAD,NLCUR,NPTM,IDGRAV                                  CEN05940
 9012     FORMAT(4I5)                                                          CEN05950
          DO 80 I=1,IMASSN                                                     CEN05960
          IF(IMASSN.EQ.0) GO TO 81                                             CEN05970
             READ(5,9000) DUMMY                                                CEN05980
      80    CONTINUE                                                          CEN05990
      81  CONTINUE                                                             CEN06000
          IF(IDAMPN.EQ.0) GO TO 91                                             CEN06010
          DO 90 I=1,IDAMPN                                                     CEN06020
             READ(5,9000) DUMMY                                                CEN06030
      90    CONTINUE                                                          CEN06040
      91  CONTINUE                                                             CEN06050
C ***     READ INITIAL CONDITIONS                                              CEN06060
          READ(5,9002) ICON                                                    CEN06070
          IF(ICON.EQ.0) GO TO 100                                              CEN06080
          CARDNR=NEQ/6.0                                                       CEN06090
          NCARD=IDINT(CARDNR)                                                  CEN06100
          TEST=CARDNR-NCARD                                                    CEN06110
          IF(TEST.GT.0.1) NCARD=NCARD+1                                        CEN06120
          DO 95 I=1,NCARD                                                      CEN06130
             READ(5,9000) DUMMY                                                CEN06140
      95     CONTINUE                                                         CEN06150
          IF(IMASS.EQ.0) GO TO 100                                             CEN06160
          DO 96 I=1,NCARD                                                      CEN06170
```

```
      READ(5,9C00) DUMMY                                                CEN06180
   96 CONTINUE                                                          CEN06190
      DO 98 I=1,NCARD                                                   CEN06200
      READ(5,9C00) DUMMY                                                CEN06210
   98 CONTINUE                                                          CEN06220
 9007 FORMAT(6E12.6)                                                    CEN06230
  1CC CONTINUE                                                          CEN06240
      NUMEL=0                                                           CEN06250
      WRITE(6,9009) NEQ,NCARD                                           CEN06260
 9009 FORMAT(///,' NEQ AND NCARD FOR IC IN GEOM1  = ',I5,10X,I5///)     CEN06270
C *** READ ELEMENT CONTROL CARDS                                        CEN06280
      DO 900 M=1,NELTYP                                                 CEN06290
      READ(5,9008)(NPAR(I),I=1,20)                                      CEN06300
      WRITE(6,901C) (NPAR(I),I=1,20)                                    CEN06310
 9008 FORMAT(2014)                                                      CEN06320
 9010 FORMAT(///,'  NPAR = ',2015///)                                   CEN06330
      MTYPE=NPAR(1)                                                     CEN06340
      NUMMAT=NPAR(16)                                                   CEN06350
      NSTRES=NPAR(13)                                                   CEN06360
C *** CALCULATE THE NUMBER OF MATERIAL CASE CARDS                       CEN06370
      IF(NPAR(15).EQ. 1) NCARD=1                                        CEN06380
      IF(NPAR(15).EQ. 2) NCARD=2+NPAR(18)                               CEN06390
      IF(NPAR(15).EQ. 3) NCARD=4                                        CEN06400
      IF(NPAR(15).EQ. 4) NCARD=4                                        CEN06410
      IF(NPAR(15).EQ. 5) NCARD=2                                        CEN06420
      IF(NPAR(15).EQ. 8) NCARD=1                                        CEN06430
      IF(NPAR(15).EQ. 9) NCARD=1                                        CEN06440
      IF(NPAR(15).EQ.10) NCARD=6                                        CEN06450
      IF(NPAR(15).EQ.11) NCARD=6                                        CEN06460
      IF(NPAR(15).NE.12) GO TO 111                                      CEN06470
      CARDNR=NPAR(17)/8.0                                               CEN06480
      NCARD=IDINT(CARDNR)                                               CEN06490
      TEST=CARDNR-NCARD                                                 CEN06500
      IF(TEST.GT.C.1) NCARD=NCARD+1                                     CEN06510
  111 CONTINUE                                                          CEN06520
      N20=20                                                            CEN06530
C *** READ MATERIAL PROPERTIES                                          CEN06540
      DO 222 J=1,NUMMAT                                                 CEN06550
      READ(5,9000) DUMMY                                                CEN06560
 9000 FORMAT(20A4)                                                      CEN06570
      DO 45 I=1,NCARD                                                   CEN06580
      READ(5,90C0) DUMMY                                                CEN06590
   45 CONTINUE                                                          CEN06600
  222 CONTINUE                                                          CEN06610
C *** READ STRESS OUTPUT TABLE CARDS                                    CEN06620
      IF(NPAR(13).EQ.0) GO TO 61                                        CEN06630
      DO 60 I=1,NSTRES                                                  CEN06640
      READ(5,9000) DUMMY                                                CEN06650
```

```
   60      CONTINUE                                                        CEN06660
   61  CONTINUE                                                            CEN06670
       IF(NPAR(14).EQ.0) NPAR(14)=1                                        CEN06680
       NEL=NPAR(14)-1                                                      CEN06690
  130  READ(5,9002) INEL,IINC                                              CEN06700
 9002  FORMAT(I5,30X,I5)                                                   CEN06710
       IF(IINC.EQ.0) IINC=1                                                CEN06720
       READ(5,9004) (INP(I),I=1,8)                                         CEN06730
       READ(5,9004) (INP(I),I=9,N20)                                       CEN06740
 9004  FORMAT(12I5)                                                        CEN06750
  140  NEL=NEL+1                                                           CEN06760
       NREL(NEL)=NEL                                                       CEN06770
       ML=INEL-NEL                                                         CEN06780
       IF(ML) 150,155,160                                                  CEN06790
  150  WRITE(6,8000)NEL                                                    CEN06800
 8000  FORMAT(//5X,'WARNING - ERROR IN ELEMENT ',I5//)                     CEN06810
C ***  NO GENERATION OF NODE POINTS REQUIRED                               CEN06820
  155  DO 156 I=1,N20                                                      CEN06830
           NP(I)=INP(I)                                                    CEN06840
           NCONT(I,NEL)=NP(I)                                              CEN06850
  156      CONTINUE                                                        CEN06860
       GO TO 162                                                           CEN06870
C ***  GENERATION OF NODE POINTS REQUIRED                                  CEN06880
  160  DO 161 I=1,N20                                                      CEN06890
           IF(NP(I).EQ.0) GO TO 161                                        CEN06900
           NP(I)=NP(I)+KN                                                  CEN06910
           NCONT(I,NEL)=NP(I)                                              CEN06920
  161      CONTINUE                                                        CEN06930
  162  CONTINUE                                                            CEN06940
       NUMEL=NUMEL+1                                                       CEN06950
       IF(NEL.EQ.NPAR(2)) RETURN                                           CEN06960
       IF(NEL.LT.INEL) GO TO 140                                           CEN06970
       KN=IINC                                                             CEN06980
       GO TO 130                                                           CEN06990
  900      CONTINUE                                                        CEN07000
       END                                                                 CEN07010
```

APPENDIX D

PROGRAM KCONT LISTING

```
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     *
C     *  PROGRAM KCONT
C     *
C     *  THIS PROGRAM READS AN 8-20 NODE ADINA INPUT DECK AND
C     *  DETERMINES THE UNIDENTIFIED NODE LOCATIONS TO YIELD
C     *  THE COORDINATES AND CONNECTIVITY FOR A 27 NODE BRICK
C     *  MESH.  THE OUTPUT IS PRINTED ON THE LINE PRINTER
C     *  AND WRITTEN ON USER DEFINED FILES 58 AND 59.
C     *
C     *  FILES:
C     *     FT58F001-COORDINATES OF ALL NODES WRITTEN IN
C     *       SEQUENCE AS FOLLOWS:  NODE NUMBER,
C     *       X-COORDINATE,Y-COORDINATE,Z-COORDINATE.
C     *
C     *     FT59F001-CONNECTIVITY ARRAY DIMENSIONED 27 BY
C     *       NUMEL.  STORED IN SEQUENCE BY ROWS.
C     *
C     *  INPUT DATA REQUIREMENTS:
C     *
C     *  CARD 1
C     *    VARIABLE     COLUMN     REMARKS
C     *
C     *     NUMNP        1-10       NUMBER OF NODES IN INPUT
C     *                             MESH.
C     *     NUMEL       11-20       NUMBER OF ELEMENTS IN INPUT
C     *                             MESH
C     *  PLACE HERE THE ADINA INPUT DECK FROM THE TITLE CARD
C     *  TO THE LAST CONNECTIVITY CARD INCLUSIVE.
C     *
C     *  WRITTEN BY:  L.R. EASTERLING NPS, MONTEREY CA., FEB 1978
C     *
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      COMMON A(30000)
      DATA A/30000*0/
      COMMON/IPARA/NUMNP,NUMEL
      READ(5,2000)NUMNP,NUMEL
 2000 FORMAT(2I10)
      MTOT=30000
      N1=1
```

```
      N2=N1+27*NUMEL*2                                                  EAS00420
      N3=N2+27*NUMEL*2                                                  EAS00430
      N4=N3+27*NUMEL*2                                                  EAS00440
      N5=N4+20*NUMEL                                                    EAS00450
      N6=N5+27*NUMEL                                                    EAS00460
      N7=N6+27*NUMEL*2                                                  EAS00470
      N8=N7+NUMEL                                                       EAS00480
      N9=N8+6*NUMEL                                                     EAS00490
      NLAST=N9+12*NUMEL                                                 EAS00500
      IF(NLAST.GT.MTOT)GO TO 10                                         EAS00510
      CALL TOTAL(A(N1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8),       EAS00520
     1 A(N9))                                                           EAS00530
      STOP                                                              EAS00540
   10 WRITE(6,1000)NLAST                                                EAS00550
 1000 FORMAT(//5X,'MTOT SHOULD BE INCREASED TO A VALUE OF ',I5//)       EAS00560
      STOP                                                              EAS00570
      END                                                               EAS00580
      SUBROUTINE TOTAL(XPT,YPT,ZPT,NCONT,KCONT,NUMPT,NREL,NFACE,        EAS00590
     1 NLINE)                                                           EAS00600
      IMPLICIT REAL*8(A-H,O-Z)                                          EAS00610
      DIMENSION NLINE(12,1),NFACE(6,1)                                  EAS00620
      COMMON/IPARA/NUMNP,NUMEL                                          EAS00630
      DIMENSION XPT(1),YPT(1),ZPT(1),NCONT(20,1),KCONT(27,1),           EAS00640
     1 NUMPT(1),NREL(1)                                                 EAS00650
      DIMENSION NCON(20),COD(20,3)                                      EAS00660
      DIMENSION NORD(19),IFACE(4,6),ILINE(2,12)                         EAS00670
      DIMENSION CNAT(3,19)                                              EAS00680
      DATA NORD/9,10,11,12,13,14,15,16,17,18,19,20,21,22,               EAS00690
     123,24,25,26,27/                                                   EAS00700
      DATA IFACE/1,2,6,5,2,3,7,6,3,4,8,7,1,4,8,5,1,2,3,4,5,6,7,8/       EAS00710
      DATA ILINE/1,2,2,3,3,4,4,1,5,6,6,7,7,8,8,5,1,5,2,6,3,7,4,8/       EAS00720
      DATA CNAT/0.0D0,1.0D0,1.0D0,-1.0D0,0.0D0,1.0D0,                   EAS00730
     10.0D0,-1.0D0,1.0D0,1.0D0,0.0D0,1.0D0,0.0D0,1.0D0,-1.0D0,          EAS00740
     2-1.0D0,0.0D0,-1.0D0,0.0D0,-1.0D0,-1.0D0,1.0D0,0.0D0,-1.0D0,       EAS00750
     31.0D0,1.0D0,0.0D0,-1.0D0,1.0D0,0.0D0,-1.0D0,-1.0D0,0.0D0,         EAS00760
     41.0D0,-1.0D0,0.0D0,0.0D0,0.0D0,0.0D0,0.0D0,1.0D0,0.0D0,           EAS00770
     5-1.0D0,0.0D0,0.0D0,0.0D0,-1.0D0,0.0D0,1.0D0,0.0D0,0.0D0,          EAS00780
     60.0D0,0.0D0,1.0D0,0.0D0,0.0D0,-1.0D0/                             EAS00790
      CALL RDADIN(XPT,YPT,ZPT,NCONT,NREL,NUMPT)                         EAS00800
      DO 10 I=1,NUMEL                                                   EAS00810
      DO 10 J=1,27                                                      EAS00820
   10 KCONT(J,I)=0                                                      EAS00830
      DO 20 I=1,NUMEL                                                   EAS00840
      DO 20 J=1,20                                                      EAS00850
   20 KCONT(J,I)=NCONT(J,I)                                             EAS00860
      R=0.0D0                                                           EAS00870
      S=0.0D0                                                           EAS00880
      T=0.0D0                                                           EAS00890
```

```
      NN2=NUMNP                                                         EAS00900
      DO 30 I=1,NUMEL                                                   EAS00910
      NN2=NN2+1                                                         EAS00920
      DO 40 J=1,20                                                      EAS00930
      NCON(J)=NCONT(J,I)                                                EAS00940
      K=NCON(J)                                                         EAS00950
      COD(J,1)=0.0D0                                                    EAS00960
      COD(J,2)=0.0D0                                                    EAS00970
      COD(J,3)=0.0D0                                                    EAS00980
      IF(K.EQ.0)GO TO 40                                                EAS00990
      COD(J,1)=XPT(K)                                                   EAS01000
      COD(J,2)=YPT(K)                                                   EAS01010
      COD(J,3)=ZPT(K)                                                   EAS01020
   40 CONTINUE                                                          EAS01030
      CALL ADCRD(R,S,T,COD,NCON,I,XX,YY,ZZ)                             EAS01040
      XPT(NN2)=XX                                                       EAS01050
      YPT(NN2)=YY                                                       EAS01060
      ZPT(NN2)=ZZ                                                       EAS01070
   30 KCONT(21,I)=NN2                                                   EAS01080
      DO 50 I=1,NUMEL                                                   EAS01090
      DO 50 J=1,6                                                       EAS01100
      NFACE(J,I)=0.0D0                                                  EAS01110
      DO 50 K=1,4                                                       EAS01120
      L=IFACE(K,J)                                                      EAS01130
   50 NFACE(J,I)=NFACE(J,I)+KCONT(L,I)                                  EAS01140
      DO 3000 I=1,NUMEL                                                 EAS01150
      DO 3000 J=1,12                                                    EAS01160
      I1=ILINE(1,J)                                                     EAS01170
      I2=ILINE(2,J)                                                     EAS01180
 3000 NLINE(J,I)=KCONT(I1,I)+KCONT(I2,I)                                EAS01190
      DO 70 I=1,NUMEL                                                   EAS01200
      DO 70 J=1,19                                                      EAS01210
      K=NORD(J)                                                         EAS01220
      IF(KCONT(K,I).NE.0) GO TO 70                                      EAS01230
      NN2=NN2+1                                                         EAS01240
      R=CNAT(1,J)                                                       EAS01250
      S=CNAT(2,J)                                                       EAS01260
      T=CNAT(3,J)                                                       EAS01270
      DO 80 M=1,20                                                      EAS01280
      COD(M,1)=0.0D0                                                    EAS01290
      COD(M,2)=0.0D0                                                    EAS01300
      COD(M,3)=0.0D0                                                    EAS01310
      NCON(M)=NCONT(M,I)                                                EAS01320
      N=NCON(M)                                                         EAS01330
      IF(N.EQ.0)GO TO 80                                                EAS01340
      COD(M,1)=XPT(N)                                                   EAS01350
      COD(M,2)=YPT(N)                                                   EAS01360
      COD(M,3)=ZPT(N)                                                   EAS01370
```

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STRESS ANALYSIS OF CERAMIC TURBINE BLADES BY FINITE ELEMENT MET--ETC(U)
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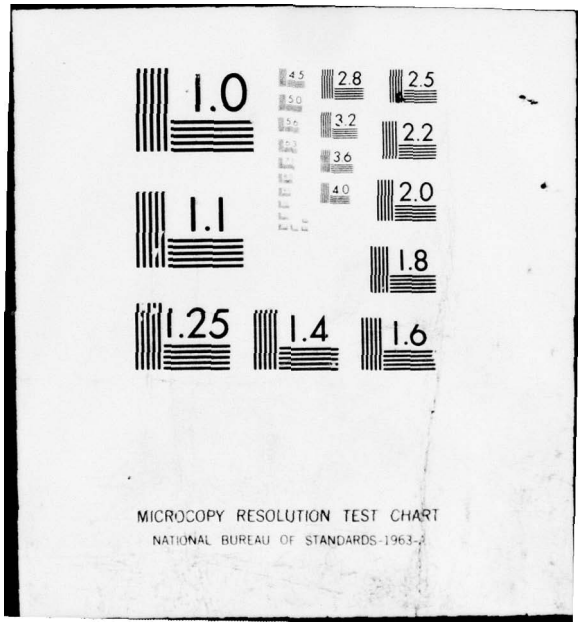
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
   80 CONTINUE                                                          EAS01380
      CALL ADCRD(R,S,T,COD,NCON,I,XX,YY,ZZ)                             EAS01390
      XPT(NN2)=XX                                                       EAS01400
      YPT(NN2)=YY                                                       EAS01410
      ZPT(NN2)=ZZ                                                       EAS01420
      IF(K.LE.20)GO TO 5000                                             EAS01430
      DO 90 II=1,NUMEL                                                  EAS01440
      DO 90 JJ=1,6                                                      EAS01450
      KK=NORD(JJ+13)                                                    EAS01460
      IF(NFACE(JJ,II).NE.NFACE(J-13,I))GO TO 90                         EAS01470
      KTR=0                                                             EAS01480
      DO 111 L=1,4                                                      EAS01490
      LL=IFACE(L,J-13)                                                  EAS01500
      DO 111 MM=1,8                                                     EAS01510
      IF(KCONT(MM,II).EQ.KCONT(LL,I))KTR=KTR+1                          EAS01520
  111 CONTINUE                                                          EAS01530
      IF(KTR.EQ.4)KCONT(KK,II)=NN2                                      EAS01540
   90 CONTINUE                                                          EAS01550
      GO TO 70                                                          EAS01560
 5000 CONTINUE                                                          EAS01570
      DO 4000 II=1,NUMEL                                                EAS01580
      DO 4000 J5=1,12                                                   EAS01590
      KK=NORD(J5)                                                       EAS01600
      IF(NLINE(J5,II).NE.NLINE(J,I))GO TO 4000                          EAS01610
      KTR=0                                                             EAS01620
      DO 4001 L=1,2                                                     EAS01630
      LL=ILINE(L,J)                                                     EAS01640
      DO 4001 MM=1,8                                                    EAS01650
      IF(KCONT(MM,II).EQ.KCONT(LL,I))KTR=KTR+1                          EAS01660
 4001 CONTINUE                                                          EAS01670
      IF(KTR.EQ.2)KCONT(KK,II)=NN2                                      EAS01680
 4000 CONTINUE                                                          EAS01690
   70 CONTINUE                                                          EAS01700
      WRITE(6,1003)NN2                                                  EAS01710
 1003 FORMAT(//5X,I7,' DISTINCT POINTS ARE IDENTIFIED'//)               EAS01720
C     REWIND 58                                                         EAS01730
C     REWIND 59                                                         EAS01740
C     WRITE(58)NN2                                                      EAS01750
      WRITE(6,1000)                                                     EAS01760
      DO 100 I=1,NUMEL                                                  EAS01770
      WRITE(6,1001)I                                                    EAS01780
      DO 100 J=1,27                                                     EAS01790
      K=KCONT(J,I)                                                      EAS01800
  100 WRITE(6,1002)J,K,XPT(K),YPT(K),ZPT(K)                             EAS01810
      WRITE(6,1004)                                                     EAS01820
 1004 FORMAT(//5X,'NODE COORDINATES BY NODE NR'//5X,'NODE',5X,'         EAS01830
     1COORDINATES'/)                                                    EAS01840
      DO 666 I=1,NN2                                                    EAS01850
```

```
  666 WRITE(6,1005)I,XPT(I),YPT(I),ZPT(I)                                EAS01860
C 666 WRITE(58)I,XPT(I),YPT(I),ZPT(I)                                    EAS01870
C     WRITE(59)((KCONT(I,J),J=1,NUMEL),I=1,27)                           EAS01880
 1005 FORMAT(1X,I9,3F16.5)                                               EAS01890
 1000 FORMAT(////5X,'NODE COORDINATES PLUS CENTROID AND MID-FAC COORDINA EAS01900
     1TES BY ELEMENT',////)                                              EAS01910
 1001 FORMAT(/5X,'ELEMENT ',I5//5X,'NATURAL',5X,'GLOBAL'/5X,'COORD NR',  EAS01920
     1 4X,'COORD NR',8X,'X-COORD',8X,'Y-COORD',8X,'Z-COORD'/)             EAS01930
 1002 FORMAT(5X,2I10,3F15.5)                                             EAS01940
C     ENDFILE 59                                                         EAS01950
C     ENDFILE 58                                                         EAS01960
      RETURN                                                            EAS01970
      END                                                               EAS01980
      SUBROUTINE ADCRD(R,S,T,COD,NCON,IEL,XX,YY,ZZ)                     EAS01990
      IMPLICIT REAL*8(A-H,O-Z)                                          EAS02000
      DIMENSION EMI(20)                                                 EAS02010
      DIMENSION COD(20,3),PROD1(3)                                      EAS02020
      DIMENSION NCON(20)                                                EAS02030
      GP(BT) = 0.5D0*(1.0D0 + BT)                                       EAS02040
      GM(BT) = 0.5D0*(1.0D0 - BT)                                       EAS02050
      GZ(BT) = 1.0D0 - BT*BT                                            EAS02060
      ZRO = 0.0D0                                                       EAS02070
      ONE = 1.0D0                                                       EAS02080
      TWO = 2.0D0                                                       EAS02090
      EMI( 9) = GZ(R)*GP(S)*GP(T)                                       EAS02100
      IF(NCON( 9).EQ.0) EMI( 9) = ZRO                                   EAS02110
      EMI(10) = GM(R)*GZ(S)*GP(T)                                       EAS02120
      IF(NCON(10).EQ.0) EMI(10) = ZRO                                   EAS02130
      EMI(11) = GZ(R)*GM(S)*GP(T)                                       EAS02140
      IF(NCON(11).EQ.0) EMI(11) = ZRO                                   EAS02150
      EMI(12) = GP(R)*GZ(S)*GP(T)                                       EAS02160
      IF(NCON(12).EQ.0) EMI(12) = ZRO                                   EAS02170
      EMI(13) = GZ(R)*GP(S)*GM(T)                                       EAS02180
      IF(NCON(13).EQ.0) EMI(13) = ZRO                                   EAS02190
      EMI(14) = GM(R)*GZ(S)*GM(T)                                       EAS02200
      IF(NCON(14).EQ.0) EMI(14) = ZRO                                   EAS02210
      EMI(15) = GZ(R)*GM(S)*GM(T)                                       EAS02220
      IF(NCON(15).EQ.0) EMI(15) = ZRO                                   EAS02230
      EMI(16) = GP(R)*GZ(S)*GM(T)                                       EAS02240
      IF(NCON(16).EQ.0) EMI(16) = ZRO                                   EAS02250
      EMI(17) = GP(R)*GP(S)*GZ(T)                                       EAS02260
      IF(NCON(17).EQ.0) EMI(17) = ZRO                                   EAS02270
      EMI(18) = GM(R)*GP(S)*GZ(T)                                       EAS02280
      IF(NCON(18).EQ.0) EMI(18) = ZRO                                   EAS02290
      EMI(19) = GM(R)*GM(S)*GZ(T)                                       EAS02300
      IF(NCON(19).EQ.0) EMI(19) = ZRO                                   EAS02310
      EMI(20) = GP(R)*GM(S)*GZ(T)                                       EAS02320
      IF(NCON(20).EQ.0) EMI(20) = ZRO                                   EAS02330
```

```
      EMI( 1) = GP(R)*GP(S)*GP(T) - (EMI( 9) + EMI(12) + EMI(17))/TWO    EAS02340
      EMI( 2) = GM(R)*GP(S)*GP(T) - (EMI( 9) + EMI(10) + EMI(18))/TWO    EAS02350
      EMI( 3) = GM(R)*GM(S)*GP(T) - (EMI(10) + EMI(11) + EMI(19))/TWO    EAS02360
      EMI( 4) = GP(R)*GM(S)*GP(T) - (EMI(11) + EMI(12) + EMI(20))/TWO    EAS02370
      EMI( 5) = GP(R)*GP(S)*GM(T) - (EMI(13) + EMI(16) + EMI(17))/TWO    EAS02380
      EMI( 6) = GM(R)*GP(S)*GM(T) - (EMI(13) + EMI(14) + EMI(18))/TWO    EAS02390
      EMI( 7) = GM(R)*GM(S)*GM(T) - (EMI(14) + EMI(15) + EMI(19))/TWO    EAS02400
      EMI( 8) = GP(R)*GM(S)*GM(T) - (EMI(15) + EMI(16) + EMI(20))/TWO    EAS02410
      DO 700 I=1,3                                                       EAS02420
      PROD1(I)=0.000                                                     EAS02430
      DO 700 J=1,20                                                      EAS02440
  700 PROD1(I)=PROD1(I)+EMI(J)*COD(J,I)                                  EAS02450
      XX=PROD1(1)                                                        EAS02460
      YY=PROD1(2)                                                        EAS02470
      ZZ=PROD1(3)                                                        EAS02480
      RETURN                                                             EAS02490
      END                                                                EAS02500
      SUBROUTINE RDADIN(XPT,YPT,ZPT,NCCNT,NREL,NUMPT)                    EAS02510
C                                                                        EAS02520
CCC   ****************************************************************   EAS02530
CCC                                                                      EAS02540
CCC      SUBROUTINE TO READ ADINA DECK.                                  EAS02550
CCC                                                                      EAS02560
CCC   ****************************************************************   EAS02570
C                                                                        EAS02580
      IMPLICIT REAL*8 (A-H,O-Z)                                          EAS02590
      REAL*4 TITLE(20)                                                   EAS02600
      COMMON/IPARA/NUMNP,NUMEL                                           EAS02610
      COMMON/LOADS/NLOAD,NLCUR,NPTM,IGRAV                                EAS02620
      DIMENSION XPT(1),YPT(1),ZPT(1),NUMPT(1),NREL(1),NCCNT(20,1)        EAS02630
      DIMENSION IDOF(6),ID(6),IDOLD(6),NODE(20),NPAR(20)                 EAS02640
     1 ,NP(20),INP(20)                                                   EAS02650
      DATA CTEST/'X       '/                                             EAS02660
      NCARD=0                                                            EAS02670
      READ(5,9000)(TITLE(I),I=1,20)                                      EAS02680
      WRITE(6,9011)(TITLE(I),I=1,20)                                     EAS02690
 9011 FORMAT(///5X,20A4,///)                                             EAS02700
C ***  READ MASTER CONTROL CARDS                                         EAS02710
C ***  NUMNP = TOTAL NUMBER OF NODE POINTS                               EAS02720
C ***  NELTYP = NUMBER OF ELEMENT GROUPS                                 EAS02730
      READ(5,9001) NUMNP,(IDOF(I),I=1,6),NEGL,NEGNL,MODEX,NSTE          EAS02740
 9001 FORMAT(I5,6I1,I4,3I5)                                              EAS02750
      NELTYP=NEGL+NEGNL                                                  EAS02760
      NNODE=NUMNP                                                        EAS02770
      READ(5,7002) IMASS,IDAMP,IMASSN,IDAMPN                             EAS02780
 7002 FORMAT(4I5)                                                        EAS02790
      READ(5,7002) IEIG                                                  EAS02800
      READ(5,7002) ISREF,NUMREF,IEQUIT,ITEMAX                            EAS02810
```

```
      READ(5,9000) DUMMY                                                    EASO2820
      READ(5,9000) DUMMY                                                    EASO2830
      READ(5,9000) DUMMY                                                    EASO2840
C *** READ OR GENERATE NODAL POINT DATA                                     EASO2850
      NOLD=0                                                                EASO2860
      NEQ=0                                                                 EASO2870
   10 READ(5,9006)CT,N,(ID(I),I=1,6),XPT(N),YPT(N),ZPT(N),KN                EASO2880
 9006 FORMAT(A1,I4,1X,I4,5I5,3F10.0,I5)                                     EASO2890
C *** CHECK FOR CYLINDRICAL COORDINATES                                     EASO2900
      IF(CT.NE.CTEST) GO TO 12                                              EASO2910
          DUM=ZPT(N)/57.2958                                                EASO2920
          R=YPT(N)                                                          EASO2930
          YPT(N)=R*DCOS(ZPT(N)/57.2958D0)                                   EASO2940
          ZPT(N)=R*DSIN(ZPT(N)/57.2958D0)                                   EASO2950
   12 CONTINUE                                                              EASO2960
      NUMPT(N)=N                                                            EASO2970
      IF(NOLD.EQ.0) GO TO 50                                                EASO2980
C *** FOR GENERATION OF FIXED BOUNDARY CONDITIONS                           EASO2990
      DO 15 I=1,6                                                           EASO3000
      IF(IDOLD(I).EQ.-1.AND.ID(I).EQ.0) ID(I)=IDOLD(I)                      EASO3010
   15     CONTINUE                                                          EASO3020
      IF(KNOLD.EQ.0) GO TO 50                                               EASO3030
      NUM=(N-NOLD)/KNOLD                                                    EASO3040
      NUMN=NUM-1                                                            EASO3050
      IF(NUMN.LT.1) GO TO 50                                                EASO3060
C *** TO COUNT DOFS TO DETERMINE NUMBER OF IC CARDS                         EASO3070
      DO 20 I=1,6                                                           EASO3080
          IF(IDOF(I).EQ.0.AND.IDOLD(I).EQ.0) NEQ=NEQ+NUMN                   EASO3090
   20 CONTINUE                                                              EASO3100
      DX=(XPT(N)-XPT(NOLD))/NUM                                             EASO3110
      IF(CT.NE.CTEST) GO TO 21                                              EASO3120
      ROLD=YPT(NOLD)/DCOS(DUMOLD)                                           EASO3130
      RNEW=YPT(N)/DCOS(DUM)                                                 EASO3140
      DR=(RNEW-ROLD)/NUM                                                    EASO3150
      DT=(DUM-DUMOLD)/NUM                                                   EASO3160
      GO TO 22                                                              EASO3170
   21 CONTINUE                                                              EASO3180
      DY=(YPT(N)-YPT(NOLD))/NUM                                             EASO3190
      DZ=(ZPT(N)-ZPT(NOLD))/NUM                                             EASO3200
   22 CONTINUE                                                              EASO3210
      K=NOLD                                                                EASO3220
      DO 30 J=1,NUMN                                                        EASO3230
          KK=K                                                              EASO3240
          K=K+KNOLD                                                         EASO3250
          XPT(K)=XPT(KK)+DX                                                 EASO3260
           IF(CT.NE.CTEST) GO TO 26                                         EASO3270
           ROLD=ROLD+DR                                                     EASO3280
           DUMOLD=DUMOLD+DT                                                 EASO3290
```

```
            YPT(K)=ROLD*DCOS(DUMOLD)                                    EAS03300
            ZPT(K)=ROLD*DSIN(DUMOLD)                                    EAS03310
            GO TO 28                                                    EAS03320
   26       CONTINUE                                                    EAS03330
            YPT(K)=YPT(KK)+DY                                           EAS03340
            ZPT(K)=ZPT(KK)+DZ                                           EAS03350
   28       CONTINUE                                                    EAS03360
            NUMPT(K)=K                                                  EAS03370
   30       CONTINUE                                                    EAS03380
   50    NOLD=N                                                         EAS03390
         KNOLD=KN                                                       EAS03400
         DUMOLD=DUM                                                     EAS03410
C ***    TO COUNT DOFS TO DETERMINE NUMBER OF IC CARDS                  EAS03420
         DO 55 I=1,6                                                    EAS03430
            IF(IDOF(I).EQ.0.AND.ID(I).EQ.0) NEQ=NEQ+1                   EAS03440
            IDOLD(I)=ID(I)                                              EAS03450
   55       CONTINUE                                                    EAS03460
         IF(N.NE.NUMNP) GO TO 10                                        EAS03470
C ***    READ LOAD CONTROL CARDS                                        EAS03480
         READ(5,9012)NLOAD,NLCUR,NPTM,IDGRAV                            EAS03490
 9012    FORMAT(4I5)                                                    EAS03500
         DO 80 I=1,IMASSN                                               EAS03510
         IF(IMASSN.EQ.0) GO TO 81                                       EAS03520
            READ(5,9000) DUMMY                                          EAS03530
   80       CONTINUE                                                    EAS03540
   81    CONTINUE                                                       EAS03550
         IF(IDAMPN.EQ.0) GO TO 91                                       EAS03560
         DO 90 I=1,IDAMPN                                               EAS03570
            READ(5,9000) DUMMY                                          EAS03580
   90       CONTINUE                                                    EAS03590
   91    CONTINUE                                                       EAS03600
C ***    READ INITIAL CONDITIONS                                        EAS03610
         READ(5,9002) ICON                                              EAS03620
         IF(ICON.EQ.0) GO TO 100                                        EAS03630
         CARDNR=NEQ/6.0                                                 EAS03640
         NCARD=IDINT(CARDNR)                                            EAS03650
         TEST=CARDNR-NCARD                                              EAS03660
         IF(TEST.GT.0.1) NCARD=NCARD+1                                  EAS03670
         DO 95 I=1,NCARD                                                EAS03680
            READ(5,9000) DUMMY                                          EAS03690
   95       CONTINUE                                                    EAS03700
         IF(IMASS.EQ.0) GO TO 100                                       EAS03710
         DO 96 I=1,NCARD                                                EAS03720
            READ(5,9000) DUMMY                                          EAS03730
   96       CONTINUE                                                    EAS03740
         DO 98 I=1,NCARD                                                EAS03750
            READ(5,9000) DUMMY                                          EAS03760
   98       CONTINUE                                                    EAS03770
```

```
 9007 FORMAT(6E12.6)                                                    EAS03780
  100 CONTINUE                                                          EAS03790
      NUMEL=0                                                           EAS03800
      WRITE(6,9009) NEQ,NCARD                                           EAS03810
 9009 FORMAT(///,' NEQ AND NCARD FOR IC IN GEOM1  = ',I5,10X,I5///)     EAS03820
C *** READ ELEMENT CONTROL CARDS                                        EAS03830
      DO 900 M=1,NELTYP                                                 EAS03840
         READ(5,9008)(NPAR(I),I=1,20)                                   EAS03850
      WRITE(6,9010) (NPAR(I),I=1,20)                                    EAS03860
 9008 FORMAT(20I4)                                                      EAS03870
 9010 FORMAT(///,'  NPAR = ',20I5///)                                   EAS03880
         MTYPE=NPAR(1)                                                  EAS03890
      NUMMAT=NPAR(16)                                                   EAS03900
      NSTRES=NPAR(13)                                                   EAS03910
C *** CALCULATE THE NUMBER OF MATERIAL CASE CARDS                       EAS03920
      IF(NPAR(15).EQ. 1) NCARD=1                                        EAS03930
      IF(NPAR(15).EQ. 2) NCARD=2+NPAR(18)                               EAS03940
      IF(NPAR(15).EQ. 3) NCARD=4                                        EAS03950
      IF(NPAR(15).EQ. 4) NCARD=4                                        EAS03960
      IF(NPAR(15).EQ. 5) NCARD=2                                        EAS03970
      IF(NPAR(15).EQ. 8) NCARD=1                                        EAS03980
      IF(NPAR(15).EQ. 9) NCARD=1                                        EAS03990
      IF(NPAR(15).EQ.10) NCARD=6                                        EAS04000
      IF(NPAR(15).EQ.11) NCARD=6                                        EAS04010
      IF(NPAR(15).NE.12) GO TO 111                                      EAS04020
      CARDNR=NPAR(17)/8.0                                               EAS04030
      NCARD=IDINT(CARDNR)                                               EAS04040
      TEST=CARDNR-NCARD                                                 EAS04050
      IF(TEST.GT.0.1) NCARD=NCARD+1                                     EAS04060
  111 CONTINUE                                                          EAS04070
      N20=20                                                            EAS04080
C *** READ MATERIAL PROPERTIES                                          EAS04090
      DO 222 J=1,NUMMAT                                                 EAS04100
         READ(5,9000) DUMMY                                             EAS04110
 9000 FORMAT(20A4)                                                      EAS04120
         DO 45 I=1,NCARD                                                EAS04130
            READ(5,9000) DUMMY                                          EAS04140
   45       CONTINUE                                                    EAS04150
  222 CONTINUE                                                          EAS04160
C *** READ STRESS OUTPUT TABLE CARDS                                    EAS04170
      IF(NPAR(13).EQ.0) GO TO 61                                        EAS04180
      DO 60 I=1,NSTRES                                                  EAS04190
         READ(5,9000) DUMMY                                             EAS04200
   60    CONTINUE                                                       EAS04210
   61 CONTINUE                                                          EAS04220
      IF(NPAR(14).EQ.0) NPAR(14)=1                                      EAS04230
      NEL=NPAR(14)-1                                                    EAS04240
  130 READ(5,9002) INEL,IINC                                            EAS04250
```

```
 9002 FORMAT(I5,30X,I5)                                                  EAS04260
      IF(IINC.EQ.0) IINC=1                                               EAS04270
      READ(5,9004) (INP(I),I=1,8)                                        EAS04280
      READ(5,9004) (INP(I),I=9,N20)                                      EAS04290
 9004 FORMAT(12I5)                                                       EAS04300
  140 NEL=NEL+1                                                          EAS04310
      NREL(NEL)=NEL                                                      EAS04320
      ML=INEL-NEL                                                        EAS04330
      IF(ML) 150,155,160                                                 EAS04340
  150 WRITE(6,8000)NEL                                                   EAS04350
 8000 FORMAT(//5X,'WARNING - ERROR IN ELEMENT ',I5//)                    EAS04360
C *** NO GENERATION OF NODE POINTS REQUIRED                             EAS04370
  155 DO 156 I=1,N20                                                     EAS04380
          NP(I)=INP(I)                                                   EAS04390
          NCONT(I,NEL)=NP(I)                                             EAS04400
  156     CONTINUE                                                       EAS04410
      GO TO 162                                                          EAS04420
C *** GENERATION OF NODE POINTS REQUIRED                                EAS04430
  160 DO 161 I=1,N20                                                     EAS04440
          IF(NP(I).EQ.0) GO TO 161                                       EAS04450
          NP(I)=NP(I)+KN                                                 EAS04460
          NCONT(I,NEL)=NP(I)                                             EAS04470
  161     CONTINUE                                                       EAS04480
  162 CONTINUE                                                           EAS04490
      NUMEL=NUMEL+1                                                      EAS04500
      IF(NEL.EQ.NPAR(2)) RETURN                                          EAS04510
      IF(NEL.LT.INEL) GO TO 140                                          EAS04520
      KN=IINC                                                            EAS04530
      GO TO 130                                                          EAS04540
  900     CONTINUE                                                       EAS04550
      END                                                                EAS04560
```

APPENDIX E

PROGRAM STRESS LISTING

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C     * * *
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```
      N2=N1+27*NUMEL*2                                                  STR00410
      N3=N2+27*NUMEL*2                                                  STR00420
      N4=N3+27*NUMEL*2                                                  STR00430
      N5=N4+27*NUMEL*2                                                  STR00440
      N6=N5+27*NUMEL*2                                                  STR00450
      N7=N6+27*NUMEL*2                                                  STR00460
      N8=N7+NN2*2                                                       STR00470
      N9=N8+NN2*2                                                       STR00480
      N10=N9+NN2*2                                                      STR00490
      N11=N10+NN2*2                                                     STR00500
      N12=N11+NN2*2                                                     STR00510
      N13=N12+NN2*2                                                     STR00520
      N14=N13+NN2*2                                                     STR00530
      N15=N14+NN2*2                                                     STR00540
      N16=N15+NN2*2                                                     STR00550
      N17=N16+NN2*2                                                     STR00560
      N18=N17+3*NN2*2                                                   STR00570
      N19=N18+NN2                                                       STR00580
      NLAST=N19+27*NUMEL                                                STR00590
      IF(NLAST.GE.MTOT)GO TO 10                                         STR00600
      CALL STRESS(A(N1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8),      STR00610
     1A(N9),A(N10),A(N11),A(N12),A(N13),A(N14),A(N15),A(N16),A(N17),    STR00620
     2A(N18),A(N19),NN2,NUMEL)                                          STR00630
      STOP                                                              STR00640
   10 WRITE(6,1001)NLAST                                                STR00650
 1000 FORMAT(2I5)                                                       STR00660
 1001 FORMAT(///5X,'*****MTOT INSUFFICIENT-MUST BE GREATER THAN',       STR00670
     1I10////)                                                          STR00680
      STOP                                                              STR00690
      END                                                               STR00700
      SUBROUTINE STRESS (SIGX,SIGY,SIGZ,TAUXY,TAUXZ,TAUYZ,ASIGX,ASIGY,ASSTR00710
     1IGZ,ATAUXY,ATAUXZ,ATAUYZ,PSIG1,PSIG2,PSIG3,PMAX,COD,KTR,KCONT,    STR00720
     2NN2,NUMEL)                                                        STR00730
      IMPLICIT REAL*8(A-H,O-Z)                                          STR00740
      DIMENSION SIGX(27,NUMEL),SIGY(27,NUMEL),SIGZ(27,NUMEL),
     1TAUXY(27,NUMEL),TAUXZ(27,NUMEL),TAUYZ(27,NUMEL),ASIGX(NN2),
     2ASIGY(NN2),ASIGZ(NN2),ATAUXY(NN2),ATAUXZ(NN2),ATAUYZ(NN2),
     3PSIG1(NN2),PSIG2(NN2),PSIG3(NN2),PMAX(NN2),COD(3,NN2)
      DIMENSION KTR(1),KCONT(27,1)                                      STR00790
      REWIND 59                                                         STR00800
      REWIND 58                                                         STR00810
      REWIND 57                                                         STR00820
      READ(59)((KCONT(I,J),J=1,NUMEL),I=1,27)                           STR00830
      READ(58)NN2                                                       STR00840
      DO 10 I=1,NUMEL                                                   STR00850
      READ(57)IEL                                                       STR00860
      DO 10 J=1,27                                                      STR00870
      READ(57)NDUM,SIGX(J,IEL),SIGY(J,IEL),SIGZ(J,IEL),TAUXY(J,IEL),    STR00880
```

```
     1 TAUXZ(J,IEL),TAUYZ(J,IEL)                                                    STR00890
  10 CONTINUE                                                                       STR00900
     DO 20 I=1,NN2                                                                  STR00910
  20 READ(58)J,(CCD(K,J),K=1,3)                                                     STR00920
     DO 30 I=1,NN2                                                                  STR00930
     ASIGX(I)=0.0D0                                                                 STR00940
     ASIGY(I)=0.0D0                                                                 STR00950
     ASIGZ(I)=0.0D0                                                                 STR00960
     ATAUXY(I)=0.0D0                                                                STR00970
     ATAUXZ(I)=0.0D0                                                                STR00980
     ATAUYZ(I)=0.0D0                                                                STR00990
  30 KTR(I)=0                                                                       STR01000
     DO 40 I=1,NLMEL                                                                STR01010
     DO 40 J=1,27                                                                   STR01020
     K=KCONT(J,I)                                                                   STR01030
     ASIGX(K)=ASIGX(K)+SIGX(J,I)                                                    STR01040
     ASIGY(K)=ASIGY(K)+SIGY(J,I)                                                    STR01050
     ASIGZ(K)=ASIGZ(K)+SIGZ(J,I)                                                    STR01060
     ATAUXY(K)=ATAUXY(K)+TAUXY(J,I)                                                 STR01070
     ATAUXZ(K)=ATAUXZ(K)+TAUXZ(J,I)                                                 STR01080
     ATAUYZ(K)=ATAUYZ(K)+TAUYZ(J,I)                                                 STR01090
  40 KTR(K)=KTR(K)+1                                                                STR01100
     DO 50 I=1,NN2                                                                  STR01110
     ASIGX(I)=ASIGX(I)/KTR(I)                                                       STR01120
     ASIGY(I)=ASIGY(I)/KTR(I)                                                       STR01130
     ASIGZ(I)=ASIGZ(I)/KTR(I)                                                       STR01140
     ATAUXY(I)=ATAUXY(I)/KTR(I)                                                     STR01150
     ATAUXZ(I)=ATAUXZ(I)/KTR(I)                                                     STR01160
  50 ATAUYZ(I)=ATAUYZ(I)/KTR(I)                                                     STR01170
     REWIND 60                                                                      STR01180
     WRITE(60)ASIGX,ASIGY,ASIGZ,ATAUXY,ATAUXZ,ATAUYZ                                STR01190
     WRITE(6,1001)                                                                  STR01200
1001 FORMAT(////5X,'AVERAGED NODAL STRESSES'////)                                   STR01210
     DO 60 I=1,NN2                                                                  STR01220
     WRITE(6,1000)I,ASIGX(I),ASIGY(I),ASIGZ(I),ATAUXY(I),                           STR01230
    1 ATAUXZ(I),ATAUYZ(I)                                                           STR01240
  60 CONTINUE                                                                       STR01250
1000 FORMAT(1X,I6,6F16.5)                                                           STR01260
     CTHRD=1.0D0/3.0D0                                                              STR01270
     PI=3.141592654                                                                 STR01280
     DO 100 I=1,NN2                                                                 STR01290
     P=-(ASIGX(I)+ASIGY(I)+ASIGZ(I))                                                STR01300
     Q=ASIGX(I)*ASIGY(I)+ASIGY(I)*ASIGZ(I)+ASIGX(I)*ASIGZ(I)                        STR01310
    1 -ATAUXY(I)**2-ATAUXZ(I)**2-ATAUYZ(I)**2                                       STR01320
     R=-(ASIGX(I)*ASIGY(I)*ASIGZ(I)+2.0D0*ATAUXY(I)*ATAUXZ(I)*ATAUYZ(I)            STR01330
    1 -ASIGX(I)*ATAUYZ(I)**2-ASIGY(I)*ATAUXZ(I)**2-ASIGZ(I)*ATAUXY(I)**            STR01340
    22)                                                                             STR01350
     A=(3.0D0*Q-P**2)/3.0D0                                                         STR01360
```

```
      B=(2.0D0*P**3-9.0D0*P*Q+27.0D0*R)/27.0D0                                   STR01370
      AB=(B**2)/4.0D0+(A**3)/27.0D0                                             STR01380
      IF(AB)400,300,200                                                         STR01390
  200 WRITE(6,2000)I,AB,A,B,P,Q,R                                               STR01400
      PSIG1(I)=11111111.                                                        STR01410
      PSIG2(I)=PSIG1(I)                                                         STR01420
      PSIG3(I)=PSIG1(I)                                                         STR01430
      GO TO 100                                                                 STR01440
  300 AA=(-B/2.0D0)**0THRD                                                      STR01450
      BB=AA                                                                     STR01460
      PSIG1(I)=AA*2.0D0-P/3.0D0                                                 STR01470
      PMAX(I)=PSIG1(I)                                                          STR01480
      PSIG2(I)=-AA-P/3.0D0                                                      STR01490
      PSIG3(I)=PSIG2(I)                                                         STR01500
      IF(PSIG2(I).GT.PSIG1(I))PMAX(I)=PSIG2(I)                                  STR01510
      GO TO 100                                                                 STR01520
  400 PHI=DARCOS((-B/2.0D0)/DSQRT((-A**3)/27.0D0))                              STR01530
      PSIG1(I)=2.0D0*DSQRT(-A/3.0D0)*DCOS(PHI/3.0D0)-P/3.0D0                    STR01540
      PSIG2(I)=2.0D0*DSQRT(-A/3.0D0)*DCOS(PHI/3.0D0+2.0D0*PI/3.0D0)             STR01550
     1 -P/3.0D0                                                                 STR01560
      PSIG3(I)=2.0D0*DSQRT(-A/3.0D0)*DCOS(PHI/3.0D0+4.0D0*PI/3.0D0)             STR01570
     1 -P/3.0D0                                                                 STR01580
      PMAX(I)=PSIG1(I)                                                          STR01590
      IF(PSIG2(I).GT.PMAX(I))PMAX(I)=PSIG2(I)                                   STR01600
      IF(PSIG3(I).GT.PMAX(I))PMAX(I)=PSIG3(I)                                   STR01610
  100 CONTINUE                                                                  STR01620
      REWIND 61                                                                 STR01630
      WRITE(61)PSIG1,PSIG2,PSIG3,PMAX                                           STR01640
      WRITE(6,2001)                                                             STR01650
      DO 600 I=1,NN2                                                            STR01660
  600 WRITE(6,2002)I,PMAX(I),PSIG1(I),PSIG2(I),PSIG3(I)                         STR01670
 2000 FORMAT(///5X,'SOLUTION FOR NODE',I5,'IS IMAGINARY'//                      STR01680
     1 10X,'AB= ',G25.16/10X,'A=',G25.16/10X,'B=',G25.16/                       STR01690
     2 10X,'P= ',G25.16/10X,'Q= ',G25.16/10X,'R= ',G25.16///)                   STR01700
 2001 FORMAT(///20X,'NODAL PRINCIPAL STRESS FOR FIRST STAGE ROTOR BLADE'        STR01710
     1 ///5X,'NODE',5X,'MAXIMUM',13X,'NR 1',16X,'NR 2',16X,'NR 3'//)            STR01720
 2002 FORMAT(1X,I8,5X,4G20.11)                                                  STR01730
      ENDFILE 61                                                                STR01740
      ENDFILE 60                                                                STR01750
      RETURN                                                                    STR01760
      END                                                                       STR01770
```

APPENDIX F

PROGRAM CONTOUR PLOT DATA LISTING

```
C     ****************************************************************CTRP0010
CCC   *                                                                CTRP0020
CCC   *                                                                CTRP0030
CCC   *        PROGRAM CONTOUR PLOT DATA                               CTRP0040
CCC   *                                                                CTRP0050
CCC   *        THIS PROGRAM IS DESIGNED TO TAKE NODAL POINT DATA FROM  CTRP0060
CCC   *        AN ADINA 3-D MESH FROM FILE 58 OF PROGRAM KCONT AND PLOT CTRP0070
CCC   *        NODE LOCATION MARKS AND NODE NUMBERS FOR VARIOUS DESIRED CTRP0080
CCC   *        2-DIMENSIONAL PLANES.  PLANES MAY BE DEFINED BY SPECIFIC CTRP0090
CCC   *        COORDINATE VALUE, LIMITING COORDINATE VALUES, OR INPUT  CTRP0100
CCC   *        OF DESIRED NODE  NUMBERS TO BE PLOTTED.                 CTRP0110
CCC   *        DATA FOR CONTOUR PLOTTING CAN ALSO BE OUTPUT            CTRP0120
CCC   *        ON THE LINE PRINTER AND/OR PUNCHED CARDS.               CTRP0130
CCC   *                                                                CTRP0140
CCC   *        REQUIRED DATA DECK:                                     CTRP0150
CCC   *                                                                CTRP0160
CCC   *        CONTROL CARD 1  (FORMAT 4I10)                           CTRP0170
CCC   *                                                                CTRP0180
CCC   *            VARIABLE        COL          REMARKS                CTRP0190
CCC   *                                                                CTRP0200
CCC   *            NN2             1-10         TOTAL NUMBER OF NODES  CTRP0210
CCC   *            NPICT           11-20        TOTAL NUMBER OF        CTRP0220
CCC   *                                         DIFFERENT PLANES TO BE CTRP0230
CCC   *                                         PLOTTED                CTRP0240
CCC   *            NDMAX           21-30        HIGHEST NUMBER OF      CTRP0250
CCC   *                                         NODES  EXPECTED PER    CTRP0260
CCC   *                                         PLANE                  CTRP0270
CCC   *            NPCH            31-40        FLAG FOR PUNCHING      CTRP0280
CCC   *                                         CONTOUR PLOT DATA      CTRP0290
CCC   *                                            0 FOR PUNCHING      CTRP0300
CCC   *                                            1 FOR NO PUNCH      CTRP0310
CCC   *                                                                CTRP0320
CCC   *        NODE CARDS                                              CTRP0330
CCC   *            INPUT NPICT SETS OF CARDS.  LEAVE COLUMNS FOR       CTRP0340
CCC   *            TESTL,TESTH,ICRD BLANK IF NODES TO BE READ IN.      CTRP0350
CCC   *            FOR EQUALITY TEST INPUT TESTL=TESTH.                CTRP0360
CCC   *                                                                CTRP0370
CCC   *        CARD1  (FORMAT 20A4)  TITLE CARD FOR ANALYSIS           CTRP0380
CCC   *                               PLANE.                           CTRP0390
C     *                                                                CTRP0400
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C     *        CARD 2  (FORMAT 2F10,3I5)                                      CTRP0410
C     *                                                                       CTRP0420
C     *                                                                       CTRP0430
C     *            TESTL              1-10        LOWER LIMIT OF PLANE       CTRP0440
C     *            TESTH              11-20       HIGHER LIMIT OF PLANE      CTRP0450
C     *            ICRD               21-25       COORDINATE TO BE           CTRP0460
C     *                                           TESTED                     CTRP0470
C     *                                            1=X COORD                 CTRP0480
C     *                                            2=Y COORD                 CTRP0490
C     *                                            3=Z COORD                 CTRP0500
C     *            IRD                 26-30       FLAG FOR READING IN        CTRP0510
C     *                                           NODE NUMBERS               CTRP0520
C     *                                            0=NO CARDS READ           CTRP0530
C     *                                            1=READ NODAL PT DATA      CTRP0540
C     *                                              CARDS                   CTRP0550
C     *            ICT                31-35       NR OF NODES TO BE          CTRP0560
C     *                                           READ IN.                   CTRP0570
C     *            MX                  11-15        COORDINATE TO BE          CTRP0580
C     *                                            PLOTTED AS HOR.COMP       CTRP0590
C     *            MY                  16-20        COORDINATE TO BE          CTRP0600
C     *                                            PLOTTED AS VERT.          CTRP0610
C     *            IF IRD=1, PLACE HERE SUFFICIENT CARDS TO DEFINE           CTRP0620
C     *            NODE NUMBERS TO BE PLOTTED USING FORMAT 16I5               CTRP0630
C     *                                                                       CTRP0640
C     *        CARD 3-PLOT TITLE CARD FORMAT 20A4 ANY TITLE                   CTRP0650
C     *            TO BE PLOTTED BELOW FIRST PLOT AND ABOVE FINAL             CTRP0660
C     *            PLOT.  MAXIMUM OF 80 CHARACTERS.                           CTRP0670
C     *                                                                       CTRP0680
C     *        CARD 4 (FORMAT F10.4)                                          CTRP0690
C     *                                                                       CTRP0700
C     *            DMAGS              1-10         MAGNIFICATION OF          CTRP0710
C     *                                           COORDINATE VALUE SO        CTRP0720
C     *                                           THAT MAXIMUM DIMEN-        CTRP0730
C     *                                           SION DOES NOT              CTRP0740
C     *                                           EXCEED 9 IN.               CTRP0750
C     *                                            1=X COORD                 CTRP0760
C     *                                            2=Y COORD                 CTRP0770
C     *                                            3=Z COORD                 CTRP0780
C     *                                                                       CTRP0790
C     *        WRITTEN BY; LAEL R EASTERLING                                  CTRP0800
C     *        NPS, MONTEREY CA, FEBRUARY 1978                                CTRP0810
C     *                                                                       CTRP0820
C     *                                                                       CTRP0830
C     ************************************************************************CTRP0840
C     *                                                                       CTRP0850
C                                                                             CTRP0860
C               ****************************                                  CTRP0870
C                                                                             CTRP0880
```

```
C                MAIN PROGRAM TO DETERMINE                                      CTRP0890
C                DIMENSIONS AND CALL SUB-                                       CTRP0900
C                ROUTINES                                                       CTRP0910
C                                                                               CTRP0920
C                ******************************                                 CTRP0930
C                                                                               CTRP0940
      DIMENSION A(26000)                                                        CTRP0950
      COMMON/IPARA/NPCH                                                         CTRP0960
      MTOT=26000                                                                CTRP0970
      READ(5,1000)NN2,NPICT,NDMAX,NPCH                                          CTRP0980
      N1=1                                                                      CTRP0990
      N2=N1+NN2*2                                                               CTRP1000
      N3=N2+NN2*2                                                               CTRP1010
      N4=N3+NN2*2                                                               CTRP1020
      N5=N4+NN2*2                                                               CTRP1030
      N6=N5+NN2*2                                                               CTRP1040
      N7=N6+NN2*2                                                               CTRP1050
      N8=N7+NN2*2                                                               CTRP1060
      N9=N8+NDMAX*NPICT                                                         CTRP1070
      N10=N9+3*NN2                                                              CTRP1080
      N11=N10+NPICT                                                             CTRP1090
      N12=N11+3*NN2                                                             CTRP1100
      N13=N12+NPICT*20                                                          CTRP1110
      NLAST=N13+2*NPICT                                                         CTRP1120
      IF(NLAST.GT.MTOT)GO TO 111                                                CTRP1130
      CALL DEFPLT (A(N1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),                   CTRP1140
     1A(N8),A(N9),A(N10),A(N11),A(N12),A(N13),NN2,NPICT,NDMAX)                  CTRP1150
      STOP                                                                      CTRP1160
  111 WRITE(6,2000)NLAST                                                        CTRP1170
 2000 FORMAT(///1X,'NLAST=  ',I10,'MTOT INSUFFICIENT'///)                       CTRP1180
 1000 FORMAT(4I10)                                                              CTRP1190
      STOP                                                                      CTRP1200
      END                                                                       CTRP1210
C                                                                               CTRP1220
C                                                                               CTRP1230
C                    ****************************                               CTRP1240
C                                                                               CTRP1250
C                    SUBROUTINE TO DEVELOP ANA-                                 CTRP1260
C                    LYSIS PLANES AND CALL PLOT                                 CTRP1270
C                    ROUTINE                                                    CTRP1280
C                                                                               CTRP1290
C                    ****************************                               CTRP1300
C                                                                               CTRP1310
      SUBROUTINE DEFPLT(XX,YY,ZZ,SIG1,SIG2,SIG3,SIGMX,LVL,COORD,KTR,            CTRP1320
     1PCOORD,TITLE,MC,NN2,NPICT,NDMAX)                                          CTRP1330
      REAL*8 XX(1),YY(1),ZZ(1),SIG1(1),SIG2(1),SIG3(1),SIGMX(1)                 CTRP1340
      DIMENSION LVL(NPICT,1),COORD(NN2,1),KTR(1),PCCORD(NN2,1)                  CTRP1350
      DIMENSION TITLE(NPICT,1),MC(2,1)                                          CTRP1360
```

```
      COMMON/IPARA/NPCH                                                 CTRP1370
      DO 10 I=1,NPICT                                                   CTRP1380
      KTR(I)=0                                                          CTRP1390
      DO 10 J=1,NDMAX                                                   CTRP1400
   10 LVL(I,J)=0                                                        CTRP1410
      REWIND 58                                                         CTRP1420
      READ(58)DUM                                                       CTRP1430
      DO 20 I=1,NN2                                                     CTRP1440
   20 READ(58)IDUM,XX(I),YY(I),ZZ(I)                                    CTRP1450
      DO 35 I=1,NN2                                                     CTRP1460
      COORD(I,1)=XX(I)                                                  CTRP1470
      COORD(I,2)=YY(I)                                                  CTRP1480
      COORD(I,3)=ZZ(I)                                                  CTRP1490
   35 CONTINUE                                                          CTRP1500
      DO 30 I=1,NPICT                                                   CTRP1510
      READ(5,1002)(TITLE(I,JJ),JJ=1,20)                                 CTRP1520
 1002 FORMAT(20A4)                                                      CTRP1530
      READ(5,1000)TESTL,TESTH,ICRD,IRD,ICT,MC(1,I),MC(2,I)              CTRP1540
 1000 FORMAT(2F10.0,5I5)                                                CTRP1550
      IF(IRD.EQ.1)GO TO 111                                             CTRP1560
      DO 40 J=1,NN2                                                     CTRP1570
      IF(COORD(J,ICRD).GT.TESTL.AND.COORD(J,ICRD).LT.TESTH.OR.          CTRP1580
     1COORD(J,ICRD).EQ.TESTL)GO TO 222                                  CTRP1590
      GO TO 40                                                          CTRP1600
  222 KTR(I)=KTR(I)+1                                                   CTRP1610
      K=KTR(I)                                                          CTRP1620
      LVL(I,K)=J                                                        CTRP1630
   40 CONTINUE                                                          CTRP1640
      GO TO 30                                                          CTRP1650
  111 READ(5,1001)(LVL(I,L),L=1,ICT)                                    CTRP1660
 1001 FORMAT(16I5)                                                      CTRP1670
      KTR(I)=ICT                                                        CTRP1680
   30 CONTINUE                                                          CTRP1690
      WRITE(6,2000)                                                     CTRP1700
      DO 45 I=1,NPICT                                                   CTRP1710
      K=KTR(I)                                                          CTRP1720
   45 WRITE(6,2001)I,(LVL(I,J),J=1,K)                                   CTRP1730
      CALL MYPLOT(LVL,COORD,KTR,PCOORD,MC,NN2,NPICT,NDMAX)              CTRP1740
      CALL PLTDT(SIG1,SIG2,SIG3,SIGMX,LVL,COORD,KTR,TITLE,MC,           CTRP1750
     1NN2,NPICT)                                                        CTRP1760
 2000 FORMAT(//5X,'NODES NUMBERS BY ANALYSIS PLANE'///)                 CTRP1770
 2001 FORMAT(//5X,'PLANE NR ',I5//1X,4(1X,25I5/))                       CTRP1780
      RETURN                                                            CTRP1790
      END                                                               CTRP1800
C                                                                       CTRP1810
CC                                                                      CTRP1820
CCC                    ************************************             CTRP1830
C                                                                       CTRP1840
```

```
C                    SUBROUTINE TO PLOT ANALYSIS PLANES                    CTRP1850
C                                                                          CTRP1860
C                    ***********************************                   CTRP1870
C                                                                          CTRP1880
                                                                           CTRP1890
      SUBROUTINE MYPLOT(LVL,COORD,KTR,PCORD,MC,NN2,NPICT,NDMAX)            CTRP1900
      DIMENSION LVL(NPICT,1),KTR(1),COORD(NN2,1),PCORD(NN2,1)              CTRP1910
      DIMENSION TITLE1(20)                                                 CTRP1920
      DIMENSION MC(2,1)                                                    CTRP1930
      COMMON/IPARA/NPCH                                                    CTRP1940
      READ(5,1000)(TITLE1(I),I=1,20)                                       CTRP1950
      READ(5,1001)DMAGS                                                    CTRP1960
      DO 10 I=1,NN2                                                        CTRP1970
      DO 10 J=1,3                                                          CTRP1980
   10 PCOORD(I,J)=COORD(I,J)*DMAGS                                         CTRP1990
      CALL PLOTS                                                           CTRP2000
      CALL PLOT(-12.,3.,-3)                                                CTRP2010
      CALL PLOT(1.,0.,-3)                                                  CTRP2020
      CALL SYMBOL(0.,0.,.14,TITLE1,0.,80)                                  CTRP2030
      CALL PLOT(4.25,5.25,-3)                                              CTRP2040
      DO 20 I=1,NPICT                                                      CTRP2050
      MX=MC(1,I)                                                           CTRP2060
      MY=MC(2,I)                                                           CTRP2070
      K=KTR(I)                                                             CTRP2080
      DO 30 J=1,K                                                          CTRP2090
      L=LVL(I,J)                                                           CTRP2100
      X=PCOORD(L,MX)-.02                                                   CTRP2110
      Y=PCOORD(L,MY)-.035                                                  CTRP2120
      CALL SYMBOL(X,Y,.07,'X',0.,1)                                        CTRP2130
      X=X+.06                                                              CTRP2140
      Y=Y-.035                                                             CTRP2150
      F=FLOAT(L)                                                           CTRP2160
      CALL NUMBER(X,Y,.14,F,0.,-1)                                         CTRP2170
   30 CONTINUE                                                             CTRP2180
      CALL PLOT(-4.25,5.,-3)                                               CTRP2190
      CALL SYMBOL(0.,0.,.14,'LEVEL',0.,5)                                  CTRP2200
      F=FLOAT(I)                                                           CTRP2210
      CALL NUMBER(1.0,0.,.14,F,0.,-1)                                      CTRP2220
      CALL PLOT(4.25,5.25,-3)                                              CTRP2230
   20 CONTINUE                                                             CTRP2240
      CALL SYMBOL(-4.25,0.,.14,TITLE1,0.,19)                               CTRP2250
      CALL PLOT (-4.25,5.,-3)                                              CTRP2260
      CALL PLOTE                                                           CTRP2270
 1000 FORMAT(20A4)                                                         CTRP2280
 1001 FORMAT(F10.4,I15)                                                    CTRP2290
      RETURN                                                               CTRP2300
      END                                                                  CTRP2310
C                                                                          CTRP2320
```

```
C                ************************************                   CTRP2330
CCCCC                                                                    CTRP2340
CCCCC            SUBROUTINE TO PRINT AND PUNCH CONTOUR                   CTRP2350
CCCCC            PLOT DATA                                               CTRP2360
CCCCC                                                                    CTRP2370
C                ************************************                   CTRP2380
C                                                                        CTRP2390
      SUBROUTINE PLTDT(SIG1,SIG2,SIG3,SIGMX,LVL,COORD,KTR,TITLE,MC,      CTRP2400
     1NN2,NPICT)                                                         CTRP2410
      REAL*8 SIG1(NN2),SIG2(NN2),SIG3(NN2),SIGMX(NN2)                    CTRP2420
      DIMENSION LVL(NPICT,1),COORD(NN2,1),KTR(1)                         CTRP2430
      DIMENSION TITLE(NPICT,1),MC(2,1)                                   CTRP2440
      COMMON/IPARA/NPCH                                                  CTRP2450
      REWIND 61                                                          CTRP2460
      READ(61)SIG1,SIG2,SIG3,SIGMX                                       CTRP2470
      DO 10 I=1,NPICT                                                    CTRP2480
      MX=MC(1,I)                                                         CTRP2490
      MY=MC(2,I)                                                         CTRP2500
      IF(NPCH.EQ.0)WRITE(7,3002)(TITLE(I,JJ),JJ=1,20)                    CTRP2510
 3002 FORMAT(20A4)                                                       CTRP2520
      K=KTR(I)                                                           CTRP2530
      IF(NPCH.EQ.0)WRITE(7,3000)                                         CTRP2540
      WRITE(6,2000)I                                                     CTRP2550
      WRITE(6,3003)(TITLE(I,JJ),JJ=1,20)                                 CTRP2560
 3003 FORMAT(//5X,20A4//)                                                CTRP2570
      DO 20 J=1,K                                                        CTRP2580
      L=LVL(I,J)                                                         CTRP2590
      WRITE(6,2001)L,COORD(L,MX),COORD(L,MY)                             CTRP2600
      IF(NPCH.EQ.0)WRITE(7,2002)L,COORD(L,MX),COORD(L,MY)                CTRP2610
   20 CONTINUE                                                           CTRP2620
      IF(NPCH.EQ.0)WRITE(7,3001)                                         CTRP2630
      WRITE(6,2003)                                                      CTRP2640
      DO 30 J=1,K                                                        CTRP2650
      L=LVL(I,J)                                                         CTRP2660
      WRITE(6,2004)L,SIGMX(L)                                            CTRP2670
      IF(NPCH.EQ.0)WRITE(7,2005)L,SIGMX(L)                               CTRP2680
   30 CONTINUE                                                           CTRP2690
   10 CONTINUE                                                           CTRP2700
 2000 FORMAT(//5X,'COORDINATES OF NODES TO BE USED IN CONTOUR            CTRP2710
     1PLOT--PLANE  ',I5//)                                               CTRP2720
 2001 FORMAT(1X,I5,2F15.5)                                               CTRP2730
 2002 FORMAT(I5,2F15.5)                                                  CTRP2740
 2003 FORMAT(//5X,'STRESSES TO BE USED IN CONTOUR PLOT'//)               CTRP2750
 2004 FORMAT(1X,I5,F15.5)                                                CTRP2760
 2005 FORMAT(I5,F15.5)                                                   CTRP2770
 3000 FORMAT(6X,'FORMAT(I5,2F15.5)')                                     CTRP2780
 3001 FORMAT('ENDGRID'/6X,'FORMAT(5I5)'/'ENDGEOM'/                       CTRP2790
     16X,'FORMAT(I5,F15.5)')                                             CTRP2800
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